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MATERIALS EXPERIMENT CARRIER CONCEPTS DEFINITION STUDY PART 2

VOLUME II

TECHNICAL REPORT

TRW CONTRACT NO. NAS8-33688

17 DECEMBER 1981

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

ALABAMA 35812

TRW

DEFENSE AND SPACE SYSTEMS GROUP

ATTACHED SHUTTLE PAYLOADS ORGANIZATION

ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

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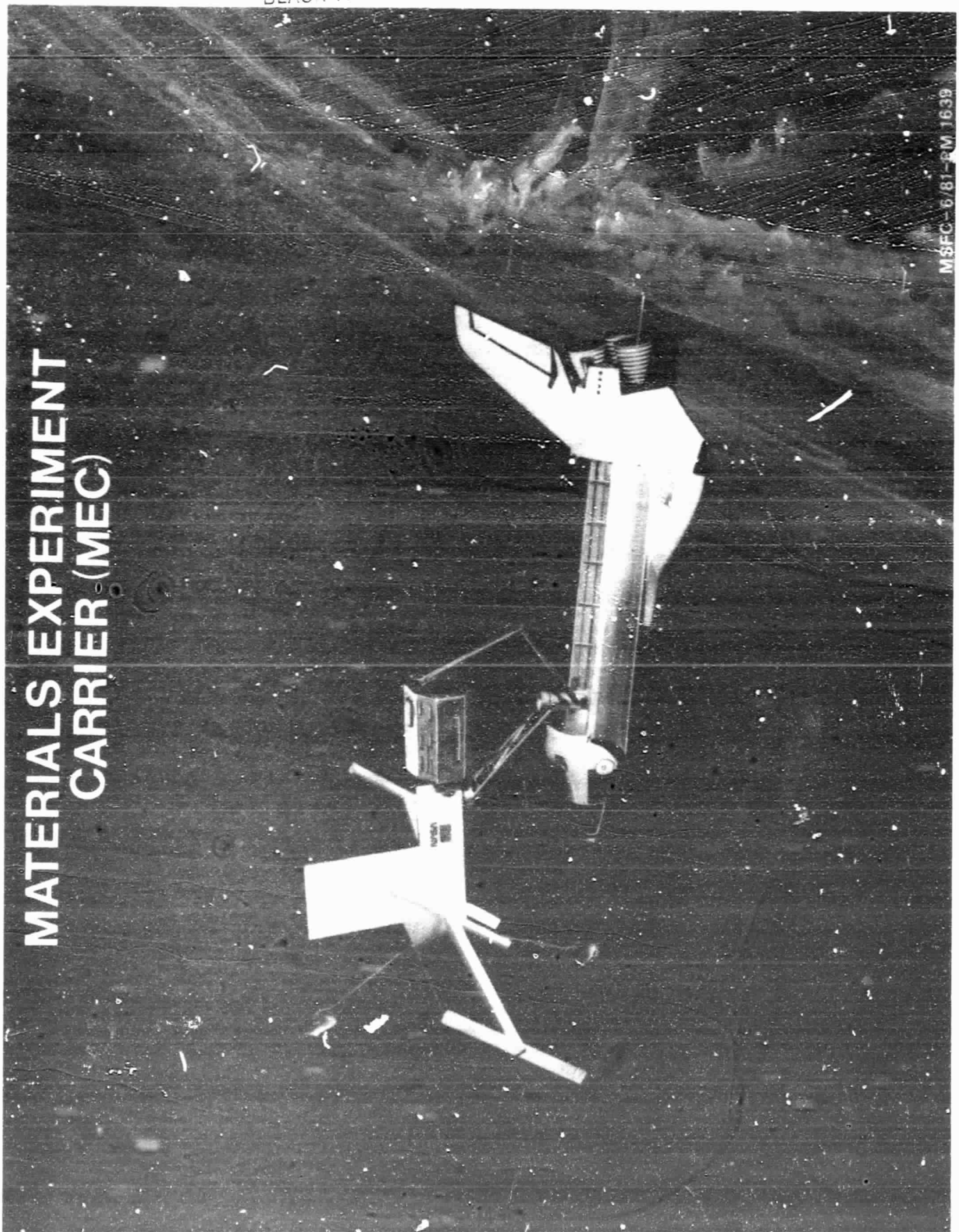

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ABBREVIATIONS AND ACRONYMS

ACS	Attitude Control Subsystem
AFD	Aft Flight Deck
CCTV	Closed-Circuit TV
CDMS	Command and Data Management System
CDR	Critical Design Review
C.G.	Center of Gravity
C.L.	Center Line
C.M.	Center of Mass
CMG	Control Moment Gyro
CNES	National Space Research Center (France)
CPU	Central Processor Unit
EOL	End of Life
EOS	Electrophoresis Operations in Space
EPDS	Electric Power Distribution System
ESA	Eruopean Space Agency
ETR	Eastern Test Range
EVA	Extra-Vehicular Activity
FM	Factory Module (ref. to EOS)
FPM	Frame Per Minute
FZP	Float Zone Processing
g	Gravity Constant
GBC	Ground-Based Control
GFE	Government Furnished Equipment
GMT	Greenwich Mean Time
GSE	Ground Support Equipment
H/K	Housekeeping
HR	Heat Rejection
HX	Heat Exchanger
I/O	Input/Output
IOC	Initial Operational Capability
IUS	Inertial Upper Stage
JSC	Johnson Space Center
KBPS	Kilobits Per Second
KSA	K_u-Band Single Access (channel)
KSC	Kennedy Space Center
L	Length
M	Mass
MB	Megabits
MBPS	Megabits Per Second
MCC	Mission Control Center

ABBREVIATIONS AND ACRONYMS (Continued)

MEA	Materials Experiment Assembly
MEC	Materials Experiment Carrier
Micro-g	Micro Gravity
MMS	Multimission Modular Spacecraft
MPS	Materials Processing in Space
MPS/SL	Materials Processing in Space/Spacelab Project
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
O&C	Operations and Checkout
OMS	Orbital Maneuvering System
OPS	Orbiter Processing Facility
PDR	Preliminary Design Review
PI	Principal Investigator
P/L	Payload
PMS	Payload Management System
PPF	Payload Processing Facility
POCC	Payload Operations Control Center
PRR	Preliminary Requirements Review
PS	Power System (no Space Platform)
RAM	Read-and-Write (Random Access) Memory
RAU	Remote Acquisition Unit
RIU	Remote Interface Unit
RM	Replacement Module (ref. to EOS)
RMS	Remote Manipulator System
ROM	Read-Only Memory
SASP	Science and Applications Space Platform
SES	Solidification Experiment System
SL	Spacelab
SM	Support Module
SMA	S-Band Multiple Access (channel)
SP	Space Platform (formerly Power System)
SPCC	Space Platform Control Center
S/S	Subsystem
SSA	Service Support Assembly
STS	Space Transportation System
T	Temperature
TCS	Thermal Control System
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
T/M	Telemetry
TMS	Teleoperator Maneuvering System
TV	Television
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VCG	Vapor Crystal Growth
VPF	Vertical Processing Facility
W	Weight
WTR	Western Test Range

1.0 INTRODUCTION

This volume presents the results of technical tasks performed during the eight months of effort on Part 2 of the Materials Experiment Carrier (MEC) Concepts Definition Study. It is constructed to reflect task results. That is, the main sections are written to present derived information and conclusions. Study methodology is minimized as it is explained in Volume I, Executive Summary.

1.1 STUDY OBJECTIVES

The overall goal of this study was to define a first step, initial MEC, that provides:

1. Effective accommodation of the NASA given baseline Materials Processing In Space (MPS) payloads.
2. Demonstration of the MPS platform concept -

   a. High priority materials processing science
   b. Multi-discipline MPS investigations
   c. Host carrier for commercial MPS payloads
   d. System economy of orbital operations

3. Potential for growth to an all-up MEC.

In essence the study objectives are summaried in this question --- What is the lowest cost, technically reasonable first step for a MEC system that meets the above goal with minimum programmatic risks?

1.2 STUDY APPROACH

The study flow of task work is shown in Figure 1-1. Study tasks 1, 2, and 4 featured analysis and trades to identify the MEC system concept options. A selected (by MSFC) MEC concept resulted from the 13 August 1981 Concept Selection Coordination Meeting at MSFC. Study tasks 3 and 4b were then keyed to developing technical definition and programmatic data on the selected concept.

The study approach and format of presentation of the generated data to MSFC relied heavily on the information derived in the Part 1 MEC effort. Full use was made of Part 1 results and data from other related NASA projects such as:

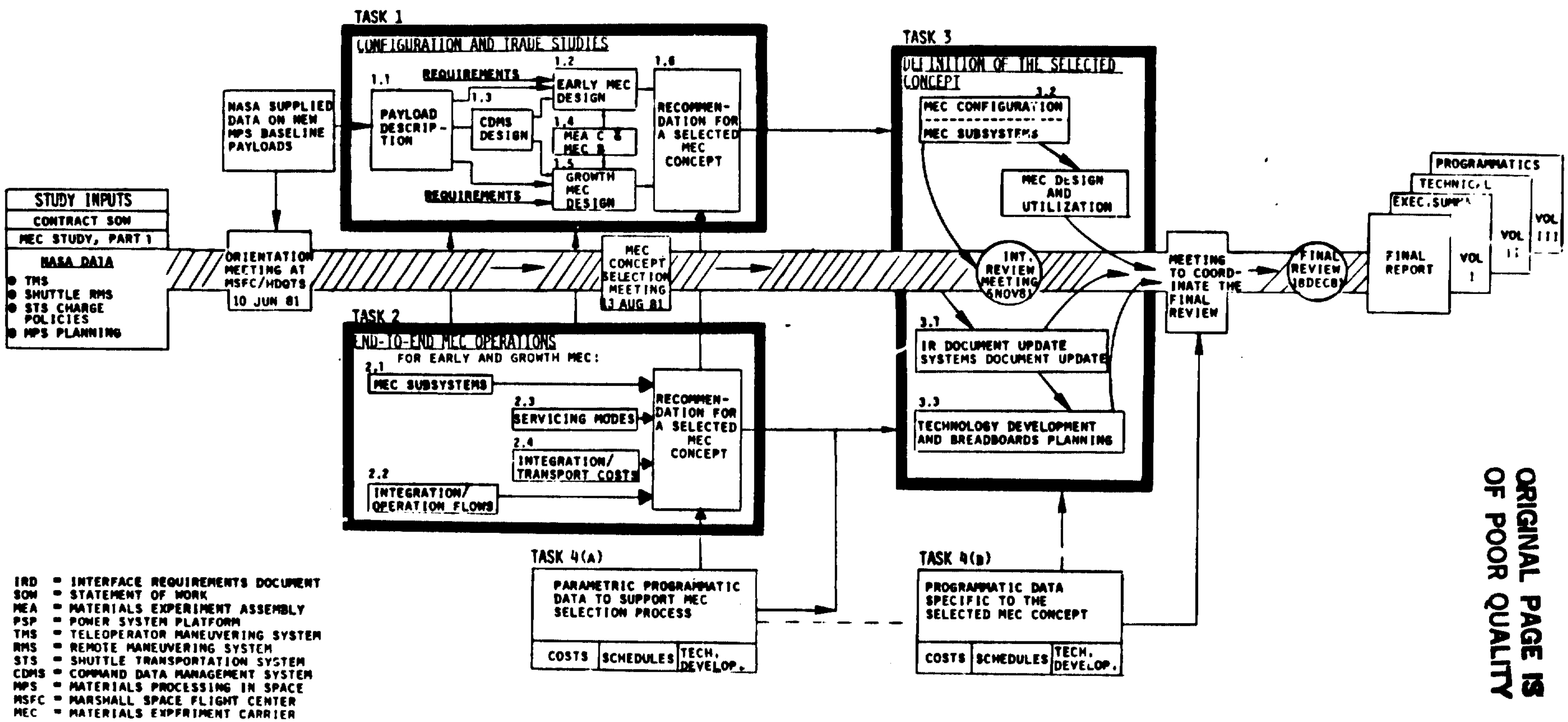

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Figure 1-1. MEC Study, Part 2, Network of Task Flow

1. Space Platform
2. Space Shuttle and Spacelab
3. Tracking and Data Relay Satellite System
4. Materials Experiment Assembly
5. MPS/Spacelab Payloads Development
6. Science and Applications Space Platform
7. Teleoperator Maneuvering System

1.3 STUDY GUIDELINES

These are the guidelines that applied to this study:

A. MEC Design

1. NASA will furnish TRW with a document giving certain specific systems requirements for the three classes of new MPS baseline MEC payloads. These payload classes are: the Materials Experiment Assembly (MEA); the Solidification Experiment System (SES); and the Electrophoresis Operations in Space (EOS).

2. MEC shall be designed so that it can evolve from an initial precursor configuration to an all-up configuration. The precursor will have orbit stay times of 90 days duration, minimum, and a nominal period of 180 days. The all-up configuration should have an open-ended on-orbit life time through on-orbit refurbishment and repair/replacement.

3. The MEC in both precursor and all-up configuration must be a general purpose carrier capable of accommodating a wide range of MPS R&D and commercial payloads. Ease of payloads and subsystems integration must be a design goal.

4. The MEC design shall accommodate automation techniques associated with processing parameters on long duration missions.

5. Payload processing systems are basically autonomous and automated.

B. MEC Operations

1. MEC always flies attached to the Space Platform (SP) and is dependent on the SP for power, thermal, stabilization, and data transmission.

2. MEC is taken to orbit to dock and fly with the SP, and returned to Earth from orbit by the Shuttle.

3. The initial operational capability (IOC) for the MEC shall be CY 1987 unless the results of the study or the availability of the SP dictate differently.

C. Cost

1. The primary design goal shall be to minimize the cost of MEC development, operations and experimental payloads, consistent with payload and safety requirements.

2. Maximum use will be made of existing and available systems and technology where feasible and cost effective.

3. The Shuttle transportation costs and mission opportunities shall be considered in MEC design optimization.

D. Interface With Space Platform Project

All MEC/Space Platform interface documentation will be distributed to and received from the MSFC MEC Study COR. There will be no direct contact between the MEC Study Team and either of the Space Platform Phase B Contractor Study Teams, unless so directed by the MEC Study COR.

1.4 BACKGROUND - MEC STUDY, PART 1

The MEC missions will be a major step beyond the short-duration MPS missions performed on Shuttle/Spacelab flights. MEC missions will evolve from short (90 to 180 day) to long duration flights that may last for a year or longer with servicing at 180-day intervals. Extended missions must be flexible to conform with MPS program schedules and commitments of the host vehicle and with priority requirements of other SP payloads.

The MEC is a self contained general purpose, versatile, and reusable carrier which will accommodate a wide range of multi-discipline R&D and commercial MPS payloads.

Two preferred configurations evolved from the Part 1 design study. They are illustrated in Figures 1-2 and 1-3. Configuration A, Figure 1-2, carries eight cylindrically shaped, autonomous payloads, each of which occupies an envelope of up to 5 m^3 of volume. The payloads are mounted for axial removal from the support structure. Access for on-orbit payload or sample exchange is provided. The berthing adapter for attachment to the SP is mounted on one side of the MEC. A thermal radiator may be carried if necessary to augment the waste heat rejection capacity normally provided by the SP. MEC subsystems include structures/mechanisms, electrical power distribution, thermal control, and command/data management, some of which are mounted externally for ease of integration and on-orbit servicing. Lesser capability MEC designs, the subject of Part 2 study efforts, are achieved through modular subtraction.

Configuration B, Figure 1-3, is an enclosed multi-sided configuration that carries seven or eight autonomous payloads, each of which occupies a

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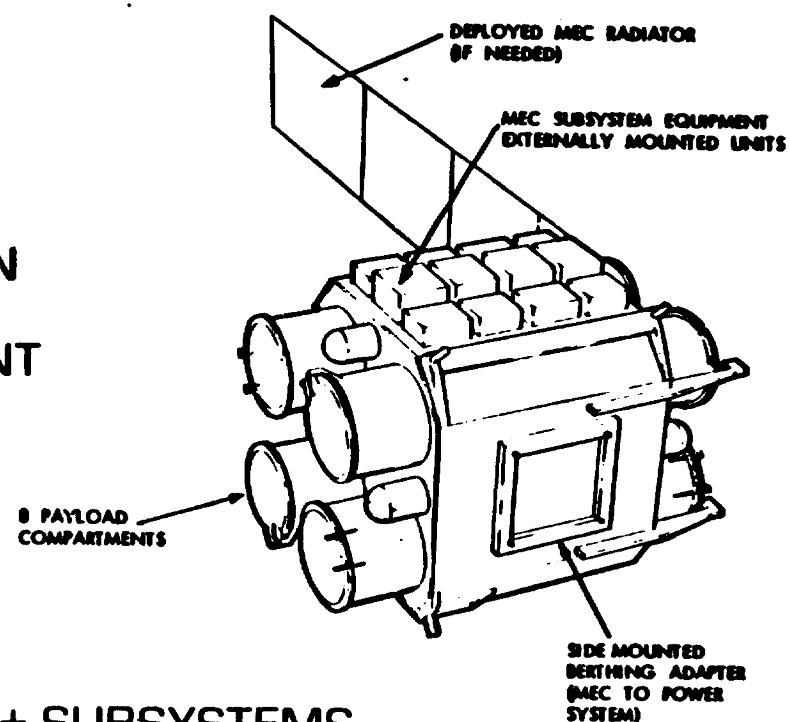
SIDE MOUNTED BERTHING ADAPTER

8 PAYLOADS ARRANGED FOR AXIAL ACCESS



SUBSYSTEMS

- STRUCTURE/MECHANISMS
- ELECTRIC POWER DISTRIBUTION
- THERMAL CONTROL
- COMMAND/DATA MANAGEMENT
- ON-BOARD CHECKOUT

CHARACTERISTICS

HEIGHT (METERS)	4.6
WIDTH (METERS)	4.6
LENGTH (METERS)	6.1

WEIGHT (KG)	3,100	STRUCTURE + SUBSYSTEMS
	11,000	PAYLOADS
	14,100	TOTAL

Figure 1-2. MEC Concept Configuration A

END MOUNTED BERTHING ADAPTER

8 PAYLOADS ARRANGED FOR LATERAL ACCESS

SUBSYSTEMS

- STRUCTURE/MECHANISMS
- ELECTRIC POWER DISTRIBUTION
- THERMAL CONTROL
- COMMAND/DATA MANAGEMENT
- ON-BOARD CHECKOUT

CHARACTERISTICS

HEIGHT (METERS)	4.3
WIDTH (METERS)	4.3
LENGTH (METERS)	5.8

WEIGHT (KG) 3,400 STRUCTURE + SUBSYSTEMS
10,700 PAYLOADS
14,100 TOTAL

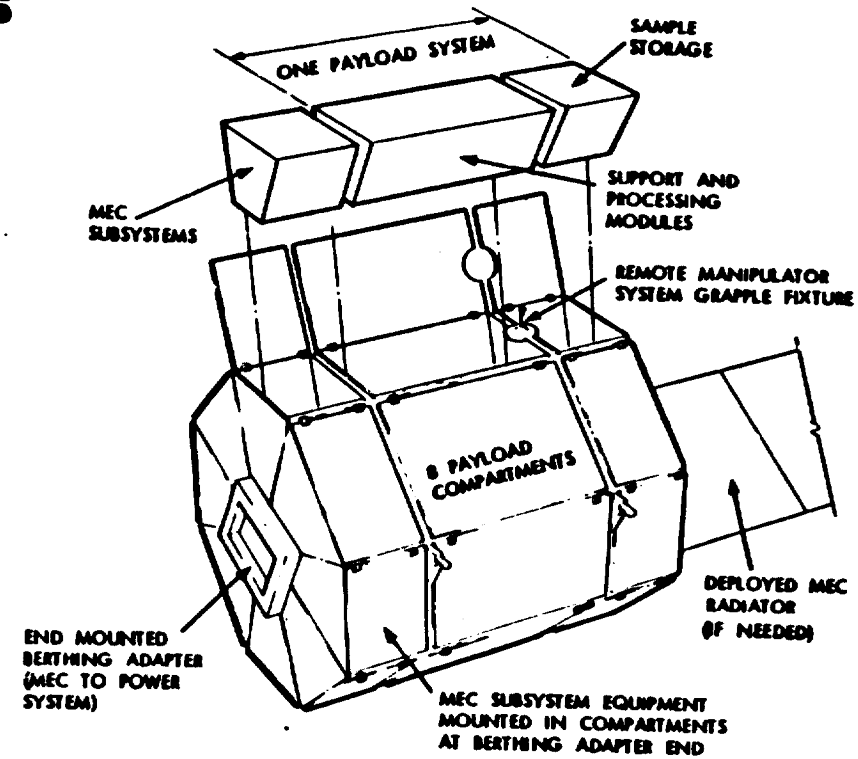


Figure 1-3. MEC Concept Configuration B

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trapezoidal prismatic envelope of 3 to 5 m^3 volume. The payloads are rail or drawer-mounted for lateral removal from the envelope. Access for on-orbit payload or sample exchange is provided. The SP berthing adapter is end-mounted. A radiator can be provided, if needed. Subsystems are the same as listed previously. They will be installed either: (1) in one of the trapezoidally shaped bays running the length of the MEC or, (2) mounted on panels in a compartment adjacent to the berthing adapter. As in Configuration A, lesser capability MEC designs can be derived through modular design.

The above two competitive concepts were carried into the study Part 2 work. As noted in later sections of this volume, a modified version of Configuration B was eventually selected as the all-up MEC concept.

1.5 STUDY EMPHASIS - MEC STUDY, PART 2

The MEC Study, Part 1 concentrated on the all-up MEC. In Part 2 the emphasis was on developing a concept for the initial MEC. The initial MEC is a first step, precursor, to the all-up version. It is a three to four MPS payload platform for early year 1987 to 1990 missions. As the reader will learn, in subsequent sections of this report, the initial MEC is a modified version of the spoked disc configuration, under study at MSFC, as the growth structure for the MSFC Materials Experiment Assembly (MEA) project. Figure 1-4 shows the initial MEC attached to the Space Platform.

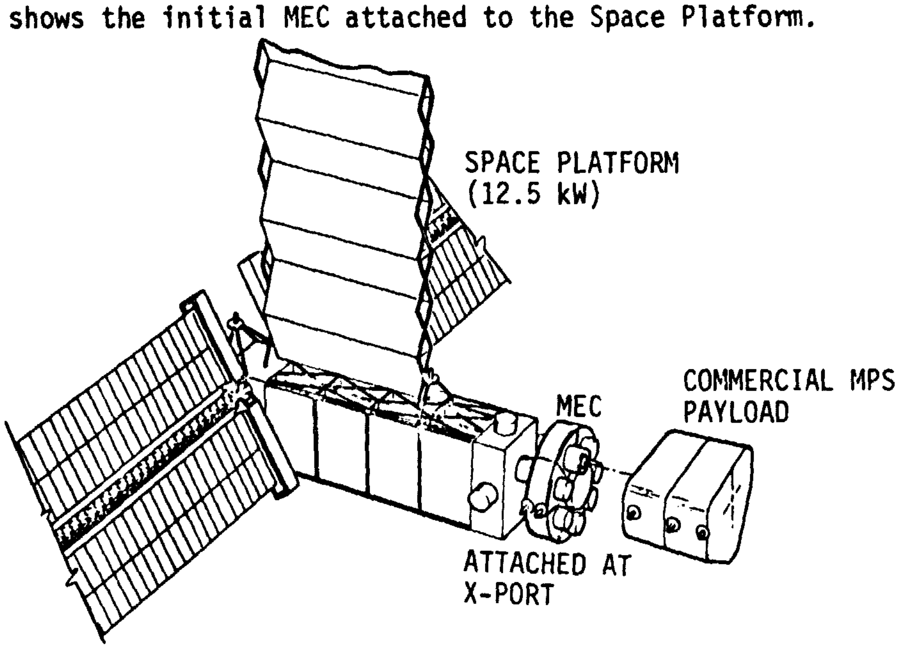

Figure 1-4. Initial MEC Attached to Space Platform

2.0 MEC PAYLOAD ACCOMMODATIONS

2.1 PAYLOAD ELEMENTS TO BE ACCOMMODATED

For each payload the elements to be considered for accommodation on MEC are the following:

- Structural - the shape, volume and weight of the payload that is required for proper operation. This will include samples, mechanical and all special components.
- Thermal - the temperature requirements and the degree of thermal control. Heat rejection requirements are also included.
- Process Control - process control requirements, uplink commands and interaction between the payload processor and the carrier processor.
- Data Acquisition/Data Handling - data storage and downlinking. These requirements include safing the data on a commercial payload to protect any proprietary interests.
- Power Control and Distribution - the power requirements and general power timeline.
- Fluid Storage - the gases and fluids are stored at each payload. The impact of this on the other payloads and payload operation must be assessed.
- Venting - individual payload venting needs are considered and the relation of payload venting to the carrier vent timeline will be taken into account.

2.2 INITIAL MEC PAYLOADS

The Materials Experiment Carrier concept accommodates multiple payloads on a single support structure. It will be designed to accommodate materials processing payloads for research, prototype and commercial operation.

Payloads developed for MEC will be based upon those developed for operation on the STS and other space operations. A list of the candidate payloads for an all-up MEC is given in Table 2-1.

MPS payload development is an evolutionary process. Payloads are or will be developed for:

- Rocket flights lasting only several minutes
- STS operation either on the pallet, in a spacelab module or mid-deck for run times from several hours up to seven days.

Table 2-1. Baseline Processor Facilities for Accommodation on the All-Up MEC

CANDIDATE PROCESSING FACILITIES FOR ALL-UP MEC
1. Advanced Solidification Experiment System A. Isothermal B. Directional Solidification
2. High Gradient Directional Solidification
3. Float Zone
4. Acoustic Containerless
5. Electromagnetic Containerless
6. Electrostatic Containerless
7. Solution Crystal Growth
8. Vapor Crystal Growth
9. Bioprocessing
10. Commercial Payloads (such as EOS)

These payloads each must be developed to a totally automated state for use on MEC. During MEC operation they must function for the period of months.

The initial complement of payloads for MEC includes the following:

Materials Experiment Assembly (MEA). The complement of MEA processors will be chosen from those that will be available from advanced MEA. These payloads will evolve from the current MEA processors which are derived from SPAR equipment.

Solidification Experiment System (SES). The SES processor was designed to a demonstration phase. Requirements used are those from the TRW/MSFC package for SES.

Electrophoresis Operation in Space (EOS). The EOS processor is a commercial payload for the preparation of biologicals. The requirements are derived from data supplied by McDonnell Douglas Aerospace Corporation (MDAC), St. Louis, Missouri.

Requirements for each of these payloads have been defined in a report written by Teledyne Brown (Reference 1). The requirements in this report were used in our derivation of the requirements for the initial MEC. The requirements as defined for the initial MEC include those for the Solidification Experiment System as obtained from PRR and PDR data. The requirements for MEA payloads were based on the Teledyne Brown data as projected

for use on MEC (Figure 2-1). Requirements for the EOS were those derived in Reference 2 augmented by information from MDAC. Requirements for the three baseline payloads are summarized in Figure 2-2 and graphically compared in Figure 2-3.

The initial MEC payloads each required 3-5 kilowatts of power. They are timelined such that the SES, EOS and one MEA payload operate simultaneously with a power demand of about 10 kW.

The EOS payload will require servicing and must be placed such that this servicing during orbit can be achieved.

The functional summary for initial MEC operation is given in Figure 2-4. From the initial payload requirements top level requirements for the initial MEC are derived. These are given in Figure 2-5. In deriving these requirements we have assumed that each payload contains all gases internal to the payload volume and that each contains its own microprocessor. This volume must be considered in the design of MEA payloads for MEC usage. Payload venting can be provided by each payload. However, the constraints on MEC venting may require that the venting be timelined as a centralized MEC function.

The requirements developed pertain to the accommodation of the payloads for the initial MEC. The accommodation of the payloads on the all-up MEC depend upon evolution of payloads and the carrier.

2.3 MEC PAYLOAD EVOLUTION

The payloads for the initial MEC will be able to conduct research and commercial experimentation with capabilities up to 180 days of processing.

Payloads that are baselined for the initial MEC will operate for up to seven days on the STS. To operate on the initial MEC for up to 180 days, several parameters must be upgraded. These include:

- Increased reliability
- Automated handling for multiple samples
- Accommodation of increased power
- Payload automation

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SPAR + MEA PAYLOADS	MASS (KG)	POWER (kW)	ADVANCED MEA	MASS (KG)	POWER (kW)
ISOTHERMAL GPRF (SPAR)	44	.90	ISOTHERMAL (1)	200	3-10
ISOTHERMAL GPF (MEA)	32	.26			
DIRECTIONAL SOLIDIFICATION (SPAR)	51	1.2			
CASTING FURNACE (SPAR)	28	0.95			
GRADIENT GPF (MEA)	38	0.875	GRADIENT	220	3-10
3-AXIS ACOUSTIC LEVITATOR (SPAR)	71	1.15	ACOUSTIC LEVITATOR	200	3-10
ACOUSTIC LEVITATOR (MEA)	36.3	2.56			
ELECTROMAGNETIC LEVITATOR (SPAR)	45	1.3	ELECTROMAGNETIC LEVITATOR	300	3-12
			FLOAT ZONE	150	3-15
			VAPOR GROWTH	100	1-9
			SOLUTION GROWTH	100	1-5

(1) SES WILL PERFORM EQUIVALENT FUNCTIONS

Figure 2-1. MEA Payloads Evolution (Teledyne Brown Data)

REQUIREMENTS / PAYLOAD	DIMENSIONS FEET (METERS)	VOLUME CUBIC FEET (METERS)	MASS LBS (KG)	ELECTRICAL POWER (KW)	ENERGY (KWH) (180 DAY MISSION)	THERMAL HEAT REJECTION (KW)
SES	8.5 x 4.9 x 5.9 (2.6 x 1.5 x 1.8)	245 (6.93)	2420 (1100)	4.6	13,000	4.7 0°C INLET TEMP.
MEA	14.0 dia x 2.5 length (4.27 x .76)	577 (16.3)	4873 (2215)	3 to 5	10,800-18,000	3-5 0°C INLET TEMP.
EOS	14.0 dia x 8 length (4.27 x 2.44)	1231 (34.8)	9988 (4540)	3.5	15,200	3.5 0°C INLET TEMP.

REQUIREMENTS / PAYLOAD	PROCESS CONTROL	DATA ACQUISITION (DOWNLINK & STORAGE)	MATERIALS (FLUIDS; GASES; SAMPLES)	SAMPLE NUMBER AND PROCESSING TIME	VENTING	EXPERIMENT ENVIRONMENT OF THE PROCESSING CHAMBER
SES	INTERNAL UPLINK COMMANDS	10 KBPS DOWNLINKED	He - 2.5 KG WITH 5.0 KG CAPACITY	• 16 SAMPLES • UP TO 400 HRS PER SAMPLE	• He 12.5g/sec DURING QUENCH POTENTIAL 1 KG/QUENCH	He AND VACUUM
MEA	INTERNAL TO EACH PAYLOAD	0.6 to 6 (DOWNLINKED)	Ar, He (TBD) O_2, AIR	• TBD SAMPLES PER PAYLOAD • TBD HRS PER SAMPLE	Ar, He Air, O_2	Ar, He Vacuum
EOS	INTERNAL USING UPLINK COMMANDS	1 KBPS DOWNLINKED	H_2O Biological Saline (TBD Quan)	CONTINUOUS TO SIX MONTHS	H_2O (TBD?)	TBD

Figure 2-2. MEC Baseline Payload Requirements on Initial MEC

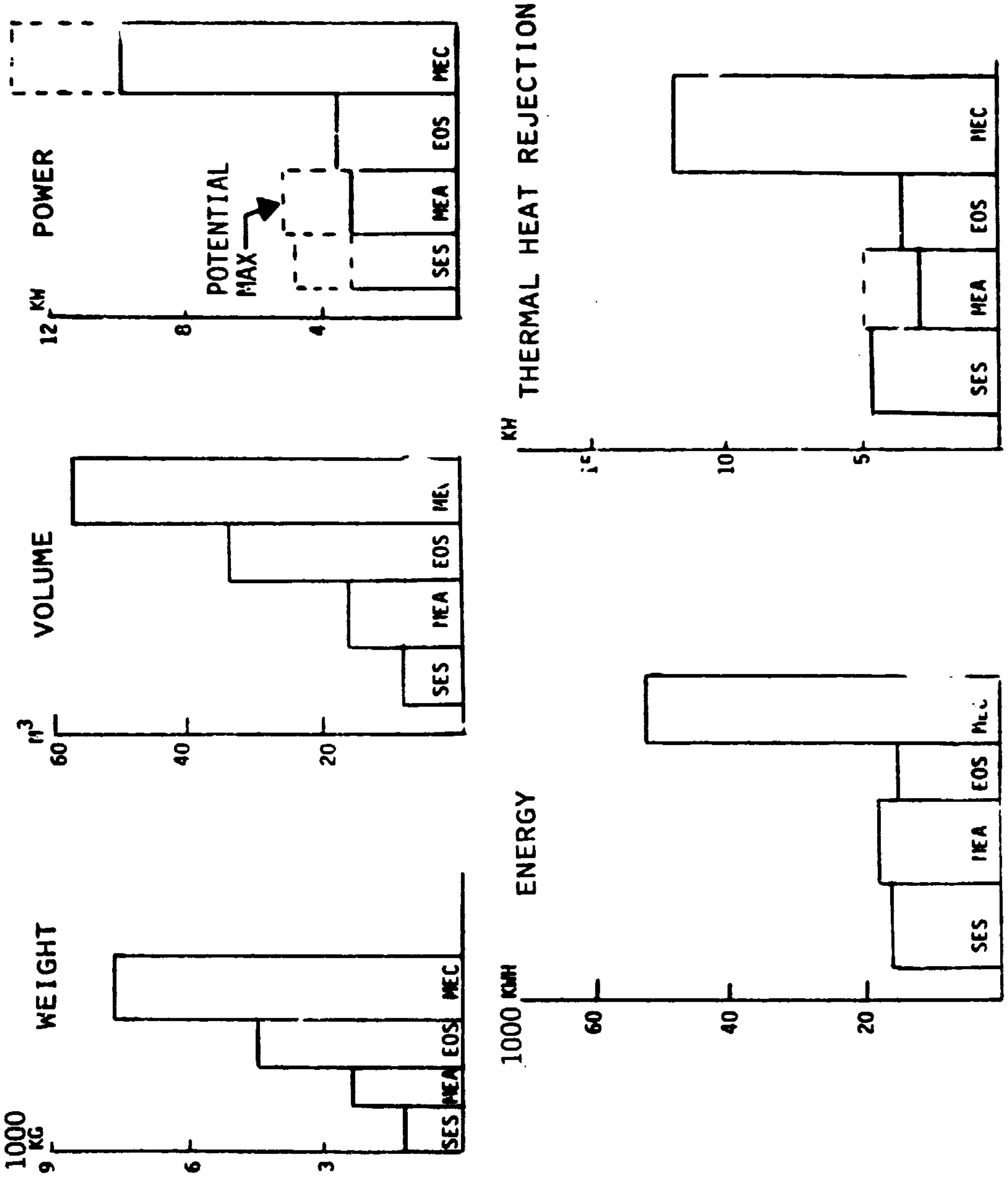

Figure 2-3. Initial MEC Payload Relationships

<u>SES</u>

- ISOTHERMAL OR DIRECTIONAL SOLIDI-FICATION MODES
- MULTIPLE SAMPLE HANDLING (ABOUT 15-25)
- MAXIMUM TEMPERATURE - 1200°C
- MAXIMUM SAMPLE SIZE 25 cm LONG x 1 cm DIAMETER
- SELF-CONTAINED COMMAND SYSTEM
- ALL DATA DOWNLINKED
- CRITICAL MEC PARAMETERS
  - DIMENSIONS
  - VOLUME
  - COMPONENT CONFIGURATION

<u>MEA</u>

- NUMBER OF LONG-TERM PAYLOADS (4-5)
- MULTIPLE SAMPLES (NUMBER TBD)
- DIMENSIONS: LENGTH NO GREATER THAN 48 INCHES; DIAMETER NO GREATER THAN 24 INCHES
- MULTIPLE PAYLOADS TO OPERATE SEQUENTIALLY
- SELF-CONTAINED COMMAND SYSTEM
- GASES REQUIRED ARE INTERNAL TO EACH MEA PAYLOAD

<u>COMMERCIAL PAYLOAD (EOS)</u>

- CONTINUOUS OPERATION
- ON-ORBIT SERVICING REQUIRED (6 MOS.)
- UPLINK COMMANDS
- DOWNLINK DATA TO SPONSOR FACILITY
- CRITICAL PARAMETERS
  - DIAMETER
  - VOLUME
  - MASS

Figure 2-4. Initial MEC Payload Function Summary

- INITIAL MEC -

ITEM	VALUE	COMMENTS
PAYLOAD DIMENSIONS	Variable	Varies with specific payload. Dimensions are MEC configuration dependent.
VOLUME (PAYLOADS)	1800 ft^3	Volume is 822 ft^3 for MEA and SES.
MASS	16290 lbs	Payload mass for MEA and SES = 6290 lbs. (max)
ELECTRIC POWER (kW)	15.0	Maximum power with SES, MEA and EOS all operating at same time. Average power will be 8 to 11 kW dependent upon timeline.
ENERGY (kWH)	39000-46000	Based on nominal timelines for 180 day mission
THERMAL HEAT REJECTION (kW)	11.2-13.2 (0°C inlet)	Minimum of 3.5 kW (EOS only).
PROCESS CONTROL	Uplink commands required	EOS and SES required capability for experiment protocol modification.
DATA ACQUISITION	12-17 kbps	Format for each experiment has not been identified. No video downlink for initial MEC.
GAS	Ar - 1 kg He - 6 kg O_2 - 29 kg	All gases are internal to the payloads.
SAMPLE NUMBER AND PROCESSING TIME	Continuous operation	Samples and sample storage are all internal to payload. Processing time for SES will be a minimum of 2000 hours. EOS is continuous operation. MEA is undefined.
VENTING	H_2O - 0.7 kg/day He - 1 kg/quench Ar, He, O_2 - TBD	Other low level venting will occur. MEA TBD.
CONTAMINATION	Vented gases and leaked materials	

Figure 2-5. MEC Top Level Integrated Payload Requirements

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Figure 2-6 shows the relationship of the initial MEC payload complement to the all-up MEC payloads. Several commercial payloads may be in operation on the a-1-up MEC. These will require special data handling if proprietary data is transmitted.

A scheme for the potential evolution of a defined MEC payload, the Solidification Experiment System, is shown in Figure 2-7. The payload has been developed in concept for a seven day mission and will handle moderately sized samples (1x25 cm). During a seven day mission only a small portion of the sample can be processed (about 1 cm). The 180 day MEC missions will enhance the capabilities of the SES as it is currently designed by allowing a longer processing zone on sample sizes that can currently be accommodated in the SES so that up to 20 cm of sample can be processed. Figure 2-8 diagrams the samples that could be accommodated. The initial MEC will be power limited. This will constrain the sample diameter and limit the melting point of materials that can be processed. The length of sample processed can be increased to the zone accommodated in a 180 day mission. The initial MEC will require no increase in the number of samples accommodated compared to the SES to be flown on an STS/SL mission. Even on the all-up MEC the number of samples required for a mission will be at most twice those on the SES designed for STS/SL. The all-up MEC will accommodate a large diameter sample with the same process zone length as on the initial MEC. Thus more volume of sample can be processed.

We have used data from Part 1 to develop a set of requirements for the all-up MEC that will meet the payload requirement is currently envisioned. These are given in Figure 2-9.

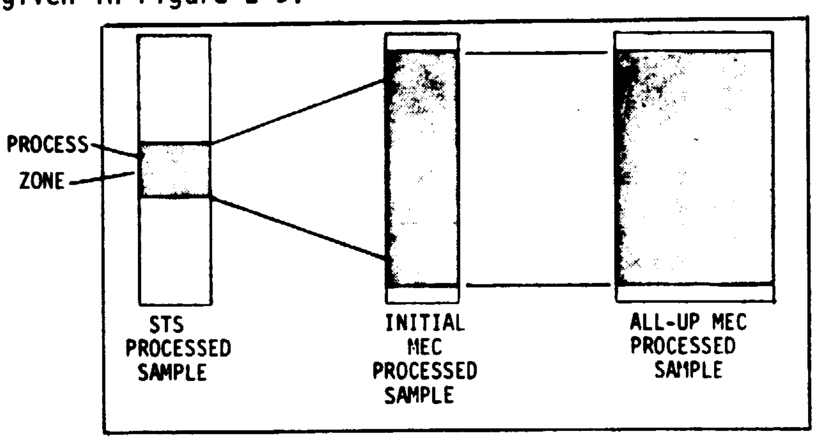

Figure 2-8. Comparison of Sample Processing Capabilities

	INITIAL MEC	ALL-UP MEC
I.	SOLIDIFICATION EXPERIMENT SYSTEM	ADVANCED SOLIDIFICATION EXPERIMENT SYSTEM - ISOTHERMAL - DIRECTIONAL SOLIDIFICATION
II.	ADVANCED MEA PROCESSORS - SPAR & INITIAL MEA PROCESSORS	
	- GRADIENT	HIGH GRADIENT DIRECTIONAL SOLIDIFICATION
	- ACOUSTIC LEVITATION - ELECTROMAGNETIC LEVITATION	CONTAINERLESS - ACOUSTIC - ELECTROMAGNETIC - ELECTROSTATIC
	- FLOAT ZONE	FLOAT ZONE
	- VAPOR GROWTH	VAPOR GROWTH
	- SOLUTION GROWTH - ELECTRO-EPITAXIAL GROWTH (COMMERCIAL)	SOLUTION CRYSTAL GROWTH
	(COMMERCIAL)	COMMERCIAL PAYLOAD
III.	ELECTROPHORESIS OPERATIONS IN SPACE	BIOPROCESSING COMMERCIAL PAYLOAD
IV.	QUICK LOOK PAYLOADS	EARLY DEVELOPMENT PAYLOADS

Figure 2-6. MPS Payloads for MEC

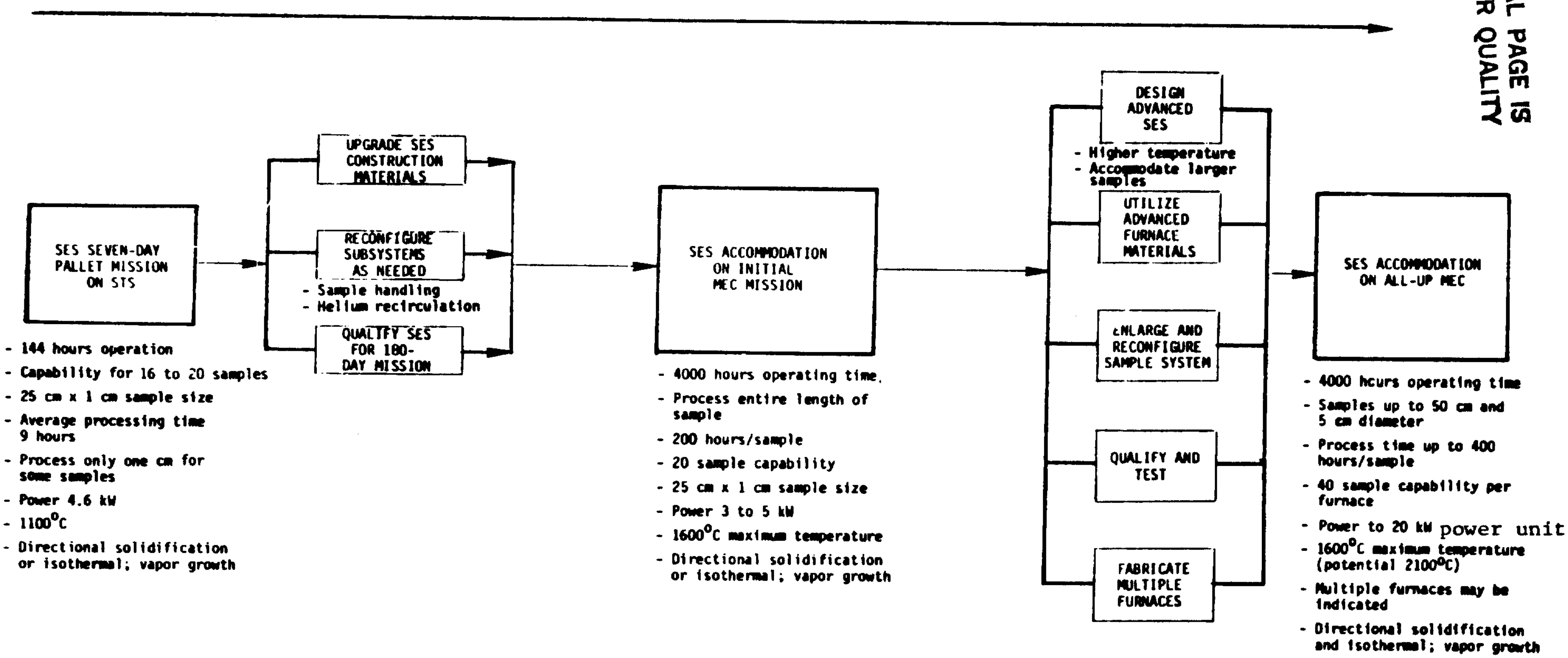

Figure 2-7. Potential Evolution of the SES Payload for MEC Flights

PAYLOAD \ FUNCTION	WEIGHT (KG)	VOLUME (M3)	POWER (KW)	ENERGY (KWHR)	MAX PROCESSING TEMPERATURE (°C)	SAMPLE PROCESS TIME (HOURS NOMINAL)	SAMPLE DIMENSION DIAM (CM)	SAMPLE DIMENSION LENGTH (CM)	SAMPLE NUMBER
● ADVANCED SOLIDIFICATION EXPERIMENT SYSTEM									
- ISOTHERMAL	1300	4.8	~ 25 kW	5×10^4	2000	20	10	30	100 (based on 180 day operation)
- DIRECTIONAL SOLIDIFICATION	1300	4.8	~ 25 kW	5×10^4	1700	100 or more	10	30	20
● HIGH GRADIENT	1000	6.3	~ 25 kW	5×10^4	1500	100-1000	10	30	20
● FLOAT ZONE	550	2.3	25 kW	4×10^4	1200	100	10	50	20
● ACOUSTIC CONTAINERLESS	1200	4.3	25 kW	1×10^4	1000	Short	10	-	Large
● ELECTROMAGNETIC CONTAINERLESS	1500	5	15 kW	1×10^4	3000	Short	2.5	-	Large
● ELECTROSTATIC CONTAINERLESS	1200	4.3	25 kW	1×10^4	TBD	Short	10	-	Large
● SOLUTION CRYSTAL GROWTH	600	1.0	10	2×10^4	1000	100	(1 Liter)	-	20
● VAPOR CRYSTAL GROWTH	600	2.0	10	1×10^4	1000	100	5	30	20
● BIOPROCESSING	500	1.6	5.0	1×10^4	30	Continuous	(4-10 KG)	-	-

REFERENCE: TRW MEC STUDY, PART 1, VOLUME II MATERIALS EXPERIMENT CARRIER PAYLOADS HANDBOOK.
TRW DOCUMENT NUMBER MPS.6-80-286, 30 JANUARY 1981

Figure 2-9. Nominal Requirements for All-Up MEC Payloads

3.0 MISSION AND SYSTEM REQUIREMENTS

This section presents MEC mission and system requirements which are updated to conform with new or revised mission objectives and guidelines. The revisions reflect modifications in the characteristics and operating modes of the host vehicle, now designated as the Space Platform (SP), from those of the former 25 kW Power System baseline reference concept published by NASA/MSFC in September 1979 (Reference 3) on which the earlier MEC design concept was based.

3.1 UPDATED MEC MISSION AND SYSTEM CONCEPT

The principal changes in the MEC mission and system concept are keyed to:

1. The projected growth of the Space Platform from an initial moderately sized vehicle providing up to 12.5 kW power to payloads into a later, full capacity version which will deliver nominally up to 25 kW.
2. An anticipated delay in SP initial operational capability (IOC) to 1987 or 1988, based on budgetary considerations.
3. The projected schedule of two Space Platform revisits per year by the Shuttle Orbiter for purposes of SP payload changeout and system resupply, maintenance or repair.
4. A revised set of early MEC materials processing payloads, to include up to seven advanced MEA type facilities, a solidification experiment system (SES), and a commercial processing facility, known as Electrophoresis Operations in Space (EOS); see the preceding section and also the recent study by Teledyne Brown Engineering (Reference 1).

Accordingly, the MEC concept addressed in the present study differs significantly from that defined in the Study Part 1 (References 4 to 8). These differences include the following:

a) The MEC design will evolve from an initial, limited capacity version, designed for use with the initial 12.5 kW SP into a full capacity "all-up" configuration that can fully utilize the resources of the later, full capacity (25 kW) Space Platform.

b) The estimated time frame for missions of the initial MEC is in the late 1980's, those of the all-up MEC is 1990 and beyond.

c) MEC mission durations, even initially, will be 180 days, as dictated by the projected SP revisits by the Shuttle. Missions of the all-up MEC may be extended to last for several revisit cycles i.e., 12 months or 18 months if necessary to meet program objectives, depending on MPS payloads and their orbital stay time requirements.

d) MEC on-orbit servicing for payload or sample exchange is not contemplated for the initial, 180-day MEC missions as there will be no Shuttle revisits at shorter time intervals. However, servicing may be required in support of all-up MEC operations if missions extend to 12 months or longer durations.

e) In the projected MEC evolution for an initial to an all-up configuration, design commonality and possible use of applicable existing hardware should be emphasized.

   Thus, the Advanced Materials Experiment Assembly, MEA-C, currently being designed by NASA/MSFC for Shuttle-based missions preceding MEC (see Reference 9) or the standard Spacelab Pallet, are leading candidates for providing the support structure or support subsystems to be used in the initial MEC design concept. They might possibly also be used as building blocks in the evolution of the all-up MEC.

Initial MEC payload accommodation requirements reflect the first-generation payload characteristics stated in the preceding section (see also Reference 2). These requirements will expand to the larger payload category previously investigated in the MEC Study, Part 1 (Reference 9).

The updated MEC system requirements (see Table 3-1) partly supersede those covered in the earlier System Requirements Document, Reference 8, dated November 1980. However, that document and the corresponding Interface Requirements Document, Reference 7, will still be useful as a source of information that is applicable in defining MEC mission and system requirements in general terms.

3.2 MISSION REQUIREMENTS

3.2.1 MEC Mission Objectives

Principal mission objectives are (a) long stay time in orbit, (b) high power level to support the complement of MEC materials processing payloads and (c) a sustained, undistrubed micro-g environment of 10^{-5}g or better. None of these objectives are achievable in Shuttle/Spacelab based materials processing activities.

3.2.2 Mission Characteristics

3.2.2.1 Initial Flight Date (IOC)

The projected initial flight date will be 1987 conforming with the IOC of the Space Platform.

Table 3-1. MEC System Requirements

DESIGN	MISSION
1. MEC WILL EVOLVE FROM INITIAL CAPABILITY (9 TO 11 KW NOMINAL, 18 KW PEAK) TO FULL ("ALL-UP") CAPABILITY (25 KW NOMINAL, 40 KW PEAK) PACED BY SP GROWTH AND MPS PAYLOADS EVOLUTION	1. MEC/SP MISSIONS CHARACTERIZED BY ● LONG STAY TIME IN ORBIT (180 DAYS AND LONGER) ● HIGH POWER LEVEL TO PAYLOADS (UP TO 25 KW NOMINAL) ● SUSTAINED, UNDISTURBED MICRO-ENVIRONMENT ($\leq 10^{-5}$g)[2]
2. PAYLOADS FOR INITIAL MEC MISSIONS WILL INCLUDE ● ADVANCED SOLIDIFICATION EXPERIMENT SYSTEM (SES) 3-5 KW ● UP TO 7 PAYLOAD FACILITIES, ADAPTED FROM ADVANCED MEA[1] 3-5 KW EACH ● ELECTROPHORESIS OPERATIONS IN SPACE (EOS) 3-5 KW	2. SIX MONTH BASELINE MISSION DURATION CONFORMS WITH PROJECTED TWICE-A-YEAR SP REVISITS BY SHUTTLE
	3. MEC IS UNCONSTRAINED AS TO ORBIT ALTITUDE AND INCLINATION, ORIENTATION AND BERTHING PORT ASSIGNMENT
3. LIMITED SP POWER CAPACITY AND ACCOMMODATION OF OTHER USERS REQUIRES TIME-SHARED MEC PAYLOAD OPERATION	4. ONLY CRITICAL MEC PROCESSES AND PROCESS PHASES REQUIRE INTERACTIVE CONTROL BY POCC, IN NEAR-REAL-TIME, VIA TDRSS/SP FORWARD AND RETURN RELAY LINKS.
4. PAYLOADS WILL OPERATE AUTONOMOUSLY, MONITORED AND CONTROLLED BY MEC CENTRAL CDMS	5. TELEOPERATOR MANEUVERING SYSTEM (TMS) MAY BE USED IN MEC DEPLOYMENT, RETRIEVAL AND SERVICING TO REDUCE ORBITER MANEUVER REQUIREMENTS
5. ACCESS TO PAYLOADS FOR ON-ORBIT SERVICING (P/L OR SAMPLE CHANGEOUT) WILL BE REQUIRED ONLY ON ALL-UP MEC	6. MEC IS A REUSABLE, VERSATILE CARRIER OF MPS PAYLOADS
6. MEC DESIGN AND OPERATION CONSTRAINED BY STS AND ASTRONAUT SAFETY REQUIREMENTS	

(1) MEA-MATERIALS EXPERIMENT ASSEMBLY, WILL FLY ORIGINALLY ON SPACE SHUTTLE AS AN ORBITER BAY PAYLOAD

(2) OCCASSIONAL MICRO-g DISTURBANCES OF ABOUT 10^{-3}g ACCEPTABLE TO SOME PAYLOADS

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3.2.2.2 Dependence on Shuttle Services

MEC shall be carried to orbit, attached to the SP and deployed into the free flying mission phase by the Shuttle Orbiter. At the end of the mission the MEC shall be retrieved by the Orbiter and returned to the ground.

During extended (all-up MEC) missions the Orbiter shall revisit the SP/MEC at least once, to perform essential services such as payload exchange, processed sample exchange, or possibly replacement of defective support systems. EOS servicing requires replacement of the Resupply Module (see Reference 1).

3.2.2.3 MEC Refurbishment and Relaunch

The same MEC vehicle shall be used repeatedly. After retrieval from orbit it shall be refurbished on the ground and/or refitted with a new payload complement and prepared for relaunch. Projected turn-around time between missions will be six months.

3.2.2.4 Mission Duration

Mission durations will be 180 days for the initial MEC and possibly longer for the all-up MEC, with up to one or even two MEC launches per year, depending on mission durations and turn-around times between missions.

3.2.2.5 MEC Orbital Altitude and Inclination

MEC will not restrict SP orbital characteristics as to altitude or inclination except for requiring operating altitudes above the level where the maximum atmospheric drag deceleration would exceed the limit of 10^{-5}g, i.e., typically 160 n.m.

Among the types of orbits being considered for SP missions low (28.5^{0}) inclination orbits will be preferable for MEC purposes because of higher Shuttle launch performance. Orbits of higher inclination, e.g., 57^{0}, provide periodic, large increases in SP power level due to reduced eclipse duration and eclipse-free conditions. MEC missions may be planned to utilize such power level increases if this is compatible with system design features, e.g., power distribution and thermal control subsystem design characteristics.

3.2.2.6 Space Platform Utilization by MEC

MEC will utilize all power output available from the SP in missions where it is the only SP payload. In missions where MEC is to share the use

of the SP with other payloads, it will utilize all power allocated to it by protocol, possibly including any increments above the nominal power level due to seasonal variation of eclipse durations.

3.2.2.7 Undisturbed MEC Micro-Gravity Environment

MEC payload operations will require a sustained, undisturbed micro-gravity environment of 10^{-5}g or better. (EOS requires 10^{-3}g).

SP velocity maneuvers for orbit maintenance or modification that would cause disturbances higher than 10^{-5}g shall be restricted to a schedule compatible with MEC payload operations, i.e., to be coincident with interruptions in materials processing. Such schedules shall be specifically established as part of mission planning.

SP reorientation maneuvers required by mission objectives of other payloads sharing the mission shall be restricted to angular rates and accelerations consistent with the required MEC micro-gravity environment, taking into account the location of sensitive MEC payloads relative to the system c.g.

Slewing rates and accelerations of articulated massive appendages carried by any companion SP payload shall be limited to levels consistent with allowable MEC payload micro-gravity limits.

3.2.2.8 Non-Interference Between MEC and Companion SP Payload Mission Requirements/Constraints

MEC and companion SP payloads shall be operated strictly according to operating modes and schedules which will avoid interference with each payload's respective mission objectives, requirements or constraints.

3.2.2.9 MEC System and MEC Payload Control Requirements

The MEC system and its payloads will operate primarily on the basis of programmed automatic sequences. These operations will be supplemented if necessary by monitoring, command and reprogramming instructions from the ground. A maximum degree of automated and autonomous operation will be desirable.

3.2.2.10 MEC Uplink and Downlink Communications

MEC uplink and downlink communications from/to MCC and POCC shall be established by SP-to-ground data links via the Tracking and Data Relay Satellite System (TDRSS).

3.2.2.11 Interactive Ground-Based Control

Interactive ground-based control modes of critical MEC processes shall be provided. In all-up MEC missions telemetry of image data will provide near real-time visual feedback to ground control personnel at the MEC Payload Operations Control Center (POCC).

3.2.2.12 MEC Utilization of Advanced Automation Technology

MEC reliance on ground-based control modes shall be minimized by increased use of advanced automation technology and artificial intelligence as these disciplines evolve to greater maturity following achievement of initial MEC operational capability.

Use of advanced automation by MEC is expected to include automatic process parameter and sequence modifications, self-adjustment of anomalous operating conditions, and detection, diagnosis and correction of malfunctions.

3.3 PAYLOAD REQUIREMENTS

3.3.1 Candidate Payloads for Initial MEC Missions

Initial MEC missions performed in the 1987 to 1990 time frame shall accommodate the following payloads (with characteristics discussed in Section 2 and Reference 1):

a) Up to seven Adanced MEA payloads including
   - Isothermal solidification
   - Gradient solidification
   - Acoustic levitator
   - Electromagnetic levitator
   - Float zone processing
   - Vapor crystal growth
   - Solution crystal growth

b) Solidification Experiment System

c) EOS

EOS will be directly attached to the Space Platform for mission continuation in the absence of MEC.

3.3.2 Candidate Payloads for All-Up MEC Missions

The following is a list of payload candidates for all-up MEC missions in the late 1980's to early 1990's time frame:

1) Solidification Experiment Processing System
2) High Gradient Furnace Processing System
3) Electromagnetic Containerless Processing System
4) Isoelectric Focusing Separation System
5) Float Zone Processing System
6) Acoustic Containerless Processing System
7) Electrostatic Containerless Processing System
8) Solution Crystal Growth Processing System
9) Vapor Crystal Growth Processing System
10) Bioprocessing Systems
11) PI Unique Systems - such as advanced MEA, also

    11.1) Space Vacuum Demonstration
    11.2) Combustion Science Facility
    11.3) Commercial Payloads Systems such as EOS
    11.4) Extraterrestrial Materials Processing Demonstrations

These are the payloads previously considered in MEC Study, Part 1 (see Reference 5 and 6). Payload candidates 1 through 10 involve materials processing facilities initially identified for inclusion in MEC mission plans. Additional experiment facilities listed as "PI Unique Systes" (items 11.1 through 11.4) were later added to the list although their requirements and characteristics are less well defined at present. Payload classes 1 through 10 have been the subject of ongoing study in ground-based laboratories; some of the experiments have been flown on rocket tests and on orbital missions e.g., Skylab. Several are currently under development for use on Shuttle/Spacelab MPS missions.

3.3.3 Evolution from R&D Experiments to Commercial Applications

MEC shall accommodate MPS payloads oriented to R&D objectives as well as payloads which support early commercial applications objectives. Generally, R&D type payloads will be used to explore effects of variation of processing parameters. Commercial application payloads typically will handle materal samples in batch processes and will demonstrate automated production feasibility. In both cases the total number of samples to be processed can be large, thus requiring long total mission durations.

3.3.4 Payload Operation Requirements

Operation of MPS payloads on orbit will require automated sequencing of activities which typically include steps such as

- Sample removal from storage
- Sample insertion into processor
- Sample heating, melting, solidification, quenching or other similar physical/metallurgical processes
- Sample removal from processor and storage
- Purging of processing chamber

Other process types such as chemical and biological processing require fewer discrete steps but involve continuous treatment of liquid sample quantities with cycled variation of state parameters such as temperature, pressure, electrostatic fields etc.

3.3.5 Processing Gas Supply and Disposal

Most of the candidate experiments require a sequence of pressurization and depressurization of the processing chamber using various gases such as helium, argon, carbon dioxide, nitrogen or oxygen. The gas will be used to produce the atmosphere appropriate for the specific process or to act as a purging agent after completion of each processing cycle.

Gas supply containers shall be included as part of the payload. Waste gas shall be disposed of or temporarily stored by a common waste management system to be provided by MEC. Non-contamination constraints imposed by the Space Platform and/or SP companion payloads may restirct the release of waste gas by MEC.

3.3.6 Instrumentation and Data Handling

MEC payloads will require instrumentation necessary to measure all relevant process data for the purpose of on-board monitoring, recording and/or telemetry. These data shall include time histories of the appropriate state variables and event sequences.

Data handling functions shall be performed individually by support equipment contained within each payload and also by the MEC data handling subsystem.

3.3.7 Imaging Requirements

Instrumentation of at least six of the ten principal MPS payload candidates projected to fly on all-up MEC missions shall include imaging systems.

Telemetry of specimen images shall permit visual monitoring of critical process phenomena by ground facilities personnel. Maximum frame rates of at least several frames per minute and simultaneous coverage by two image systems, for three-dimensional viewing, will be required in some cases. Typically, at a 500 by 500 pixels resolution and 8 bits per pixel, corresponding telemetry data rates will range from 33 Kbps to 330 Kbps per image system. Some processes may at times require maximum image data rates exceeding 1 Mbps. However, conditions under which close visual monitoring of process image data is required will occur infrequently.

3.3.8 MEC/Payload Interfaces

MEC-to-payload and internal payload interfaces shall be designed to facilitate MEC/payload integration as well as payload exchange on the ground and on orbit.

The established modular design approach for Spacelab MPS payloads to be used for MEC payloads subdivides the payload into a process support and processing module. This modular design approach permits payload subsystem commonality and standardization and is consistent with on orbit servicing/changeout objectives. Figure 3-1 illustrates this modular design concept and identifies internal interfaces in the case of a MEC float zone processing system.

Payload autonomy is to be emphasized. Each payload may carry its own power conditioning, control electronics, instrumentation, data acquisition and management, sample handling and storage, and gas/fluids. MEC subsystem trades will determine how much of these functions should be supplied by MEC subsystems.

3.3.9 Payload Access for Servicing On Orbit

Payloads carried in all-up MEC missions shall have design and interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations will include exchange either of entire payload units or only of sample magazines within payloads, and possibly the replacement of malfunctioning payload subsystems.

Servicing operations will require payload and component handling either by the Shuttle Remote Manipulator System (RMS) or manually, by a crewman. In addition, convenient and safe access to internal equipment shall be provided via access hatches of sufficiently large size.

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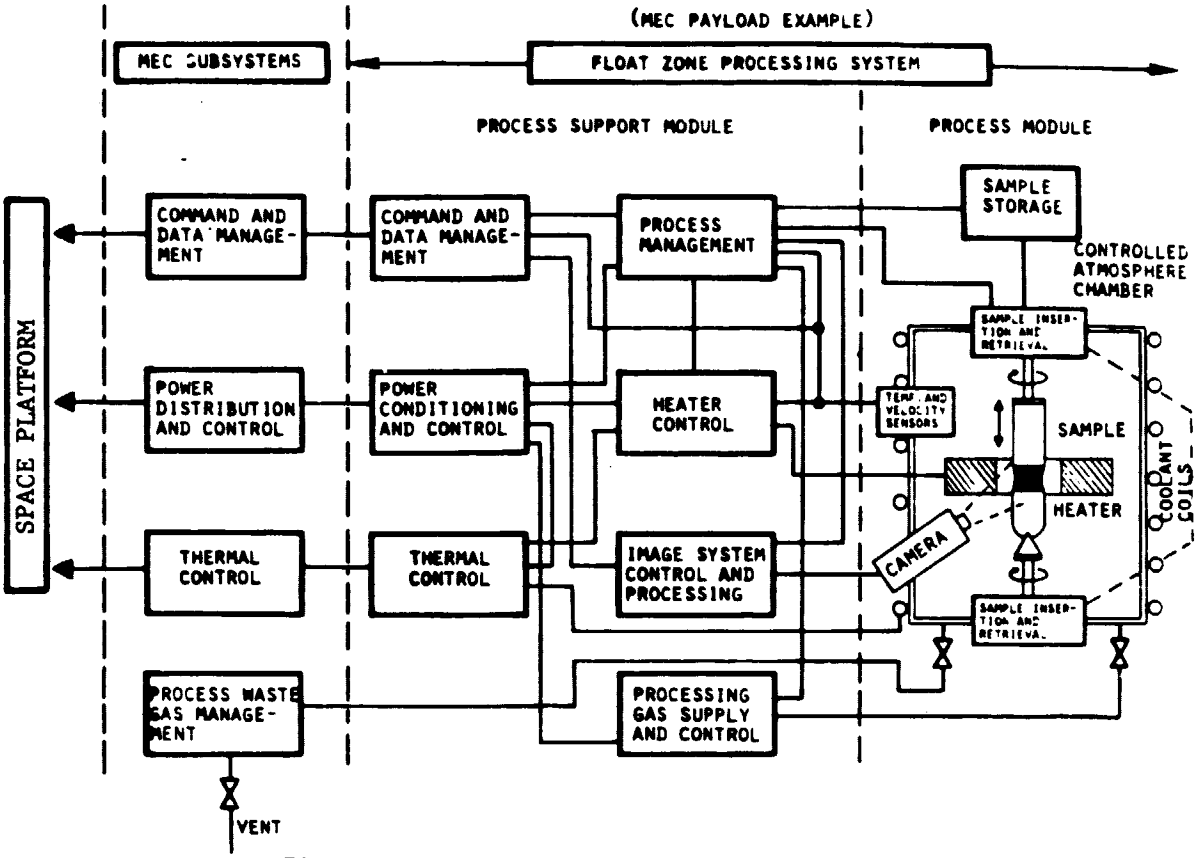

Figure 3-1. Modular Payload Schematic (All-Up MEC)

3.4 MISSION SUPPORT AND INTERFACE REQUIREMENTS BY EXTERNAL SYSTEM ELEMENTS

3.4.1 Interfacing System Elements

The MEC mission will require the support of a number of interfacing systems in orbit or on the ground (see Figures 3-2 and 3-3). In addition to the Space Platform the following external systems will be involved

(1) Shuttle Orbiter and crew
(2) Teleoperator Maneuvering System (TMS)
(3) TDRSS (space and ground segments)
(4) Ground control facilities at MCC, SPCC, and POCC
(5) Ground support equipment (GSE) and Shuttle Launch Site/Landing Site Facilities

Other external system elements which will indirectly interface with, and impose constraints on MEC include companion payloads carried by the Shuttle and companion payloads sharing the SP with MEC.

Space Platform

1. Power
2. Heat rejection
3. Data handling/telemetry channels
4. Command channels
5. Attitude stabilization

Ground Support Equipment

1. Handling
2. Shuttle integration
3. Checkout
4. Post-flight ops

POCC Via TDRSS/SP Link

1. Command and telemetry links
2. Monitor and control experiments (including real time control, as required)

Shuttle Orbiter

1. Launch
2. Deploy/retrieve (RMS)
3. Checkout
4. Power
5. Thermal protection
6. Servicing support * (RMS)
7. Safety

Orbiter Crew

1. Deploy/retrieve
2. Remote/EVA
3. On-orbit checkout
4. Servicing*

Teleoperator Maneuvering System

1. Maneuver support in SP revisits (MEC launch, retrieval, service*)
2. Remote handling of MEC or MEC payload units.

*In All-Up MEC Only

Figure 3-2. MEC External Interfaces

3.4.2 MEC/Space Platform Interfaces

The SP will provide electric power, heat rejection, data handling, communications, attitude control, propulsion and structural support. Direct interfaces include power, thermal and data transfer and structures/mechanisms. The SP also establishes and controls MEC interfaces with other SP users (companion payloads).

3.4.3 MEC/Orbiter Interfaces

The Orbiter will be used to launch, retrieve and service MEC and to provide structural support, auxiliary electric power, data handling and communication, crew support and manipulation, with or without use of the RMS, and onboard checkout/validation. Indirect Orbiter interfaces will be involved in controlling SP rendezvous, capture and berthing; SP/MEC separation and deployment; and possibly, control of Teleoperator-supported MEC deployment, retrieval and servicing operations.

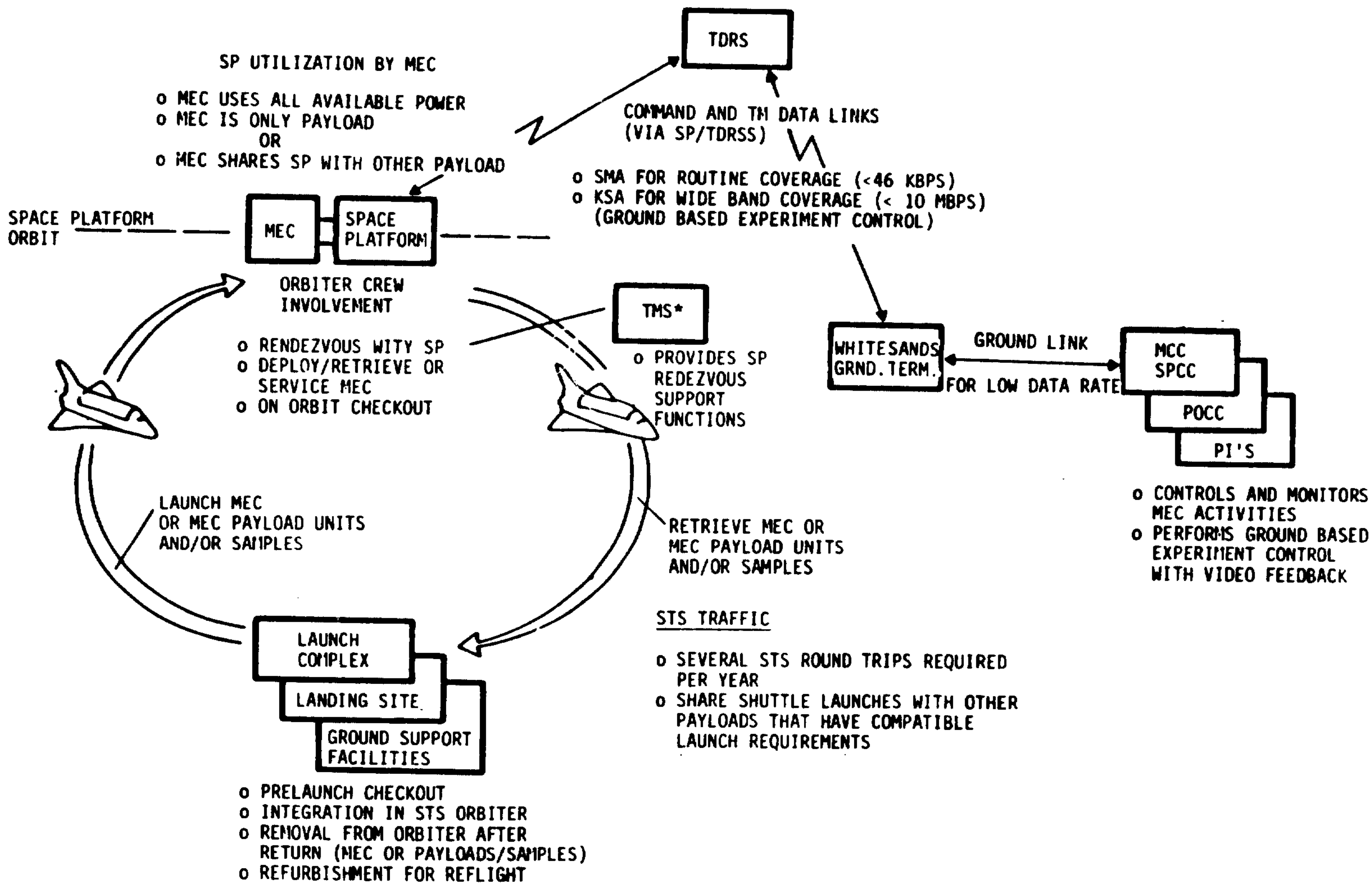

Figure 3-3. Functional Elements of MEC Mission

3.4.4 TDRSS Interface

The TDRSS will support MEC/SP ground contact (command and telemetry) requirements via SP/TDRSS communication links in the low and high data rate modes (see 3.4.5).

3.4.5 MEC/Ground Control Interfaces

The Payload Operations Control Center (POCC) will monitor and control MEC operations via TDRSS/SP communication links except at times when MEC and SP/MEC are directly or indirectly subject to Orbiter control operations and interface functions. At those times the mission will be controlled by MCC. In general, the Space Platform Control Center (SPCC) will be involved in handling all data flow to and from the SP/MEC, providing the link between the POCC and the TDRSS ground station.

3.4.6 Support by GSE and Launch Site/Landing Site Facilities

MEC will require GSE support at the system integration site, the launch and landing sites. Support by and interfaces with standard Shuttle/payload integration and handling facilities at the launch/landing sites also will be part of the overall MEC mission profile and mission planning activities.

3.5 SYSTEM DESIGN REQUIREMENTS

3.5.1 General Requirements and Design Issues

3.5.1.1 Design Guidelines

The MEC vehicle shall meet the following general requirements derived from original system design guidelines and mission objectives.

1) The initial MEC is projected to become operational by 1987, keyed to the Space Platform IOC date.
2) Both the initial and all-up MEC shall be designed for an open-ended life time achieved through refurbishment between flights. The number of required reflights has not been determined at this time.
3) The initial MEC shall be designed to accommodate 7 to 8 payloads per flight including EOS if practical (see Section 3.3). The all-up MEC shall accommodate additional and larger payloads than the initial MEC plus EOS if practical.

4) The all-up MEC design shall be consistent with, and facilitate on-orbit payload or sample changeout and subsystem/component replacement if necessary. This requires ease of payload or subsystem access by the Orbiter crew.

5) Both the initial and all-up MEC design shall provide standardized payload interfaces to facilitate payload integration or exchange on the ground, and on-orbit servicing in the case of all-up MEC.

3.5.1.2 Related Design Requirements

6) The MEC design shall be guided by weight and volume (cargo length) economy to minimize Shuttle transportation cost.

7) MEC total weight and volume shall be consistent with Shuttle cargo capacity. Adaptation to available cargo space and/or weight capacity dictated either by ride-sharing or by target orbit inclination and altitude will be required by some MEC missions. These upper limits will be determined by the Shuttle Mission Planning Office at NASA/JSC.

8) MEC shall make full use of available SP resources, i.e., electric power, heat rejection, command and data management, and communication channel capacity, either as sole user or as one of several users (payloads) of the SP.

9) MEC shall provide flexibility in the number of payloads it accommodates, preferably through modularity in structural design and subsystems, thereby conforming with SP resources availability and allocation in shared missions and with Shuttle cargo capacity. A principal objective is mission cost flexibility and potential cost savings.

3.5.2 MEC Configuration

3.5.2.1 Accommodation on Space Platform

The MEC configuration shall conform with accommodation on the +x, ±y or +z payload berthing ports of the Space Platform (see Figure 3-4) and the standard payload berthing adapters provided at these ports.

3.5.2.2 Clearance of SP Structures and of Other Payloads Attached to the SP

MEC dimensions and clearance envelope shall be within limits set by the "stay-out" volume of SP structures and appendages and of other SP users attached to adjacent payload berthing ports. Stay-out volumes for each berthing port, or conversely, the allowable volume allocated to a payload such as MEC at its assigned berthing port, still require definition by the Space Platform Project Office at NASA/MSFC. (An example of such limits for MEC attachment to the +x and +z ports is shown in Figure 4-16, next Section).

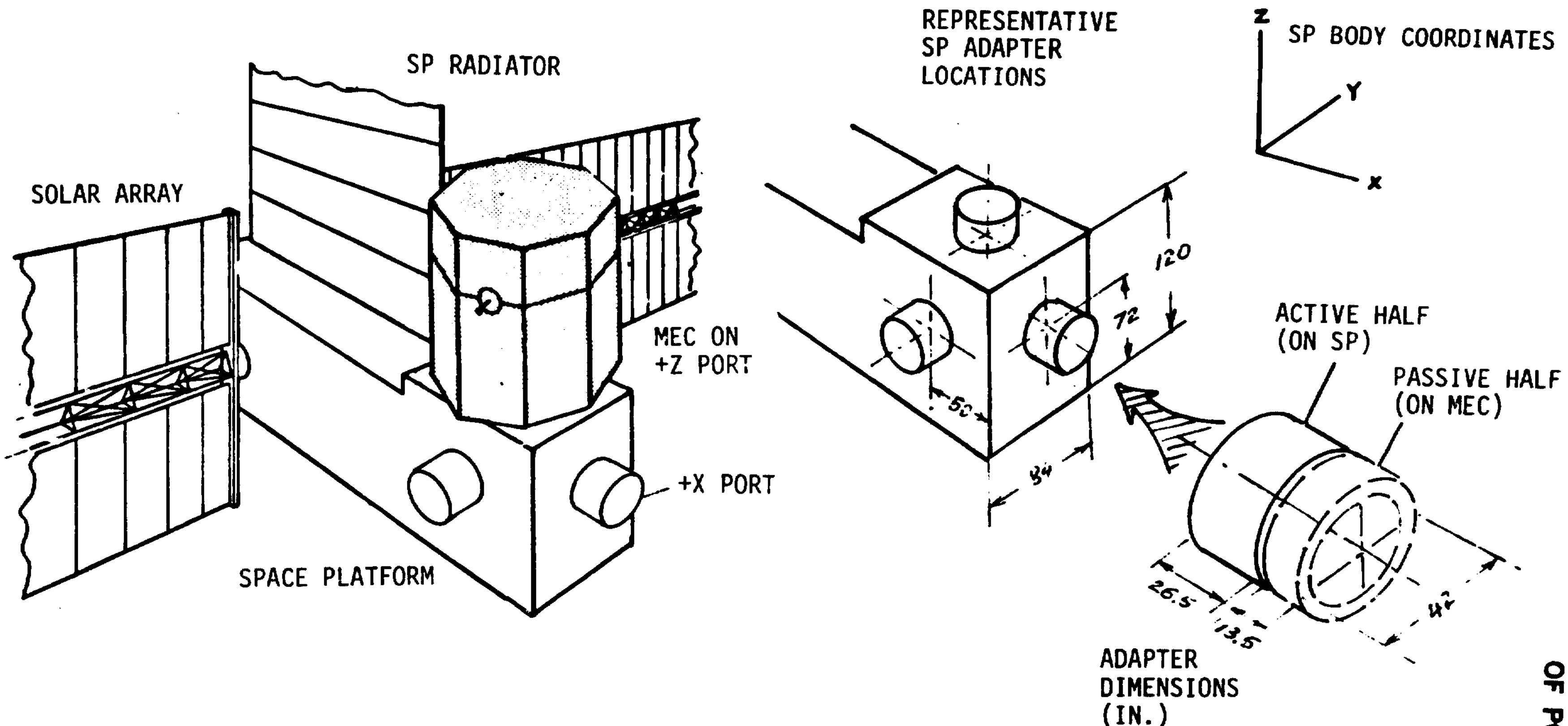

Figure 3-4. Locations of Space Platform X, Y and Z Payload Berthing Ports

The clearance envelope extends beyond the MEC outside dimensions and should include the adjacent volume required for access to, and removal of payload elements during on-orbit servicing activities.

3.5.2.3 Accommodation on Shuttle Orbiter

The MEC stowed configuration shall conform with accommodation in the Shuttle Orbiter cargo bay. Generally, two pairs of trunnions and a keel fitting shall be provided for MEC/Shuttle cargo bay attachment prior to Shuttle launch or return to the ground. The relative spacing of trunnions and keel fitting shall be in accordance with Shuttle/payload structural interface specifications (Reference 10).

3.5.2.4 RMS Grapple Fixtures

One or possibly several grapple fixtures shall be provided on the MEC structure, located to provide convenient access by the Remote Manipulator (RMS)/end effector in MEC stowing, unstowing and berthing operations.

Additional grapple fixtures shall also be provided on the payload units to permit payload attachment and detachment to/from MEC by the RMS as well as stowing and unstowing on the MEC Service Support Assembly during on-orbit servicing. Note that the payload units are too massive and bulky for manual handling by the crew during servicing activities.

3.5.2.5 Provisions for Payload Attachment

The MEC configuration shall be designed for convenient attachment or removal of payload units at any of its (standardized) berthing ports and thus facilitate payload replacement and exchange on the ground or, in case of the all-up MEC, on orbit.

3.5.2.6 Accessibility of Payloads

The all-up MEC configuration shall be designed to provide access for payload attachment or removal on orbit within a restricted clearance envelope as determined by the proximity of SP structures or appendages (such as the solar array panels and the radiator) and adjacent companion payload structures. The clearance envelope shall also reflect the space required by the Shuttle RMS/end effector to reach and be attached to the payload grapple fixture and to manipulate the payload while clearing adjacent structures. (See also paragraph 3.5.2.2).

3.5.2.7 Orbiter and Crew Safety

The MEC external configuration design shall be consistent with Orbiter and crew safety requirements in accordance with Reference 11. This shall include provisions to separate (jettison) protruding deployed/appendages (such as radiator panels if any) in the event that they cannot be retracted and restowed safely on preparing for Shuttle return from orbit. Also, the design shall not pose hazards to EVA crewmen working at or near the stowed or deployed MEC. Crew hazard elimination pertains specifically to avoidance of protruding corners, sharp edges and other design features that might snag, rip, puncture or otherwise damage a crewman's space suit (see Reference 12).

3.5.2.8 Crew Mobility Aids and Access Support

The MEC configuration shall provide crew mobility aids such as handholds and handrails as well as crew access and work support features such as receptacles for temporary foot rest and work station attachment. The configuration also shall be compatible with use by crewmen of the RMS/ Cherry Picker work platform and with attachment of that platform to the work site(s) for stability.

3.6 MEC SUBSYSTEMS

3.6.1 Support Functions Provided by Subsystems

MEC subsystems shall provide support functions required by MEC payloads, including structural support; electric power distribution and control; thermal control; command and data management; executive control of payload operations; checkout of MEC and payload status, functions and interfaces; and waste gas management.

MEC subsystems shall augment and supplement support functions which otherwise are performed by the Space Platform, viz., electric power generation, conditioning and control; heat rejection; communication and data management; executive control of MEC operations vis-a-vis those of payloads other then MEC.

Thus, in general terms, MEC subsystems shall provide the necessary functional interface services between the SP and the various MEC payloads.

3.6.2 MEC Structures and Mechanisms Subsystem

This subsystem shall provide structure support, attach mechanisms and enclosures for MEC payloads, payload support equipment and other MEC subsystems. It also shall provide the SP berthing adapter, attach fittings for Shuttle cargo bay installation, an RMS grapple fixture and crew access and mobility aids.

A principal design requirement shall be flexible/interchangeable payload accommodation by means of standardized payload adapters and interface provisions.

3.6.3 Electric Power Subsystem

Interfacing with the Space Platform or the Shuttle Orbiter, the MEC power subsystem shall receive, distribute and control conditioned power to MEC subsystems and payloads. It also shall provide auxiliary battery power needed to maintain essential subsystem functions when external power is not available, i.e., during MEC transfer operations.

3.6.4 Thermal Control

The MEC thermal control subsystem shall interface with the SP thermal control/heat rejection subsystem and provide temperature control for MEC subsystems, payloads and payload support equipment. Heat transfer to the SP-provided payload heat exchanger shall be through a pumped fluid loop connected by an umbilical at the MEC/SP interface.

An auxiliary radiator shall be provided in the all-up MEC if necessary to augment the SP heat rejection capacity.

3.6.5 Command and Data Management

The MEC command/data management subsystem (CDMS) shall support the data flow to and from MEC payloads via interfaces with the SP and/or the Shuttle Orbiter. Interfaces with mission support facilities on the ground (MCC, SPCC, and POCC) will be maintained by the SP communication subsystem via TDRSS links.

The CDMS also shall provide full control of all MEC operations and executive control of MEC payload functions and operations, based on preprogrammed or updated command sequences. The subsystem also shall perform

necessary automatic checkout and validation functions during prelaunch, orbital deployment and after on-orbit servicing. To accomplish these functions the system shall interface with the SP control computer and payload management subsystem and with MEC payload process control.

The subsystem shall autonomously control all routine MEC on orbit operations. Support by ground-based control may be provided in anomalous or critical operating conditions.

3.7 MEC DESIGN INTERFACES

3.7.1 Interface Summary

The MEC design shall provide the interfaces necessary for effective utilization of SP functions and capabilities. It also shall provide the interfaces required for accommodation by the Shuttle Orbiter and crew system during launch, retrieval (and servicing). Some of these interface requirements are discussed earlier in this section and in Section 4. Figure 3-5 shows principal interfaces between MEC and SP, Figure 3-6 those between MEC and the Orbiter.

A direct MEC interface capability with the Teleoperator Maneuvering System (TMS), Reference 13, also probably shall be required to facilitate MEC or MEC payload handling and transfer between the Orbiter and the SP during MEC deployment, retrieval or servicing in a mission scenario where SP/Orbiter rendezvous and berthing should be avoided. Further study and definition of this interface will be necessary.

3.7.2 Space Platform Interfaces

MEC/SP interface provisions shall include the structural/mechanical, electric power, thermal control, command and data handling, and payload management interfaces.

Structural/mechanical interface requirements for compatibility with standard SP berthing port adapters are coverd in Paragraphs 3.5.2.5 and 3.6.2.

The electrical power interface shall be via umbilical connectors which are provided on the MEC/SP berthing adapters. MEC will utilize high voltage (120 VDC) and low voltage (30 VDC) power supplied by the SP power subsystem via five separate bus lines. The nominal, maximum power to be

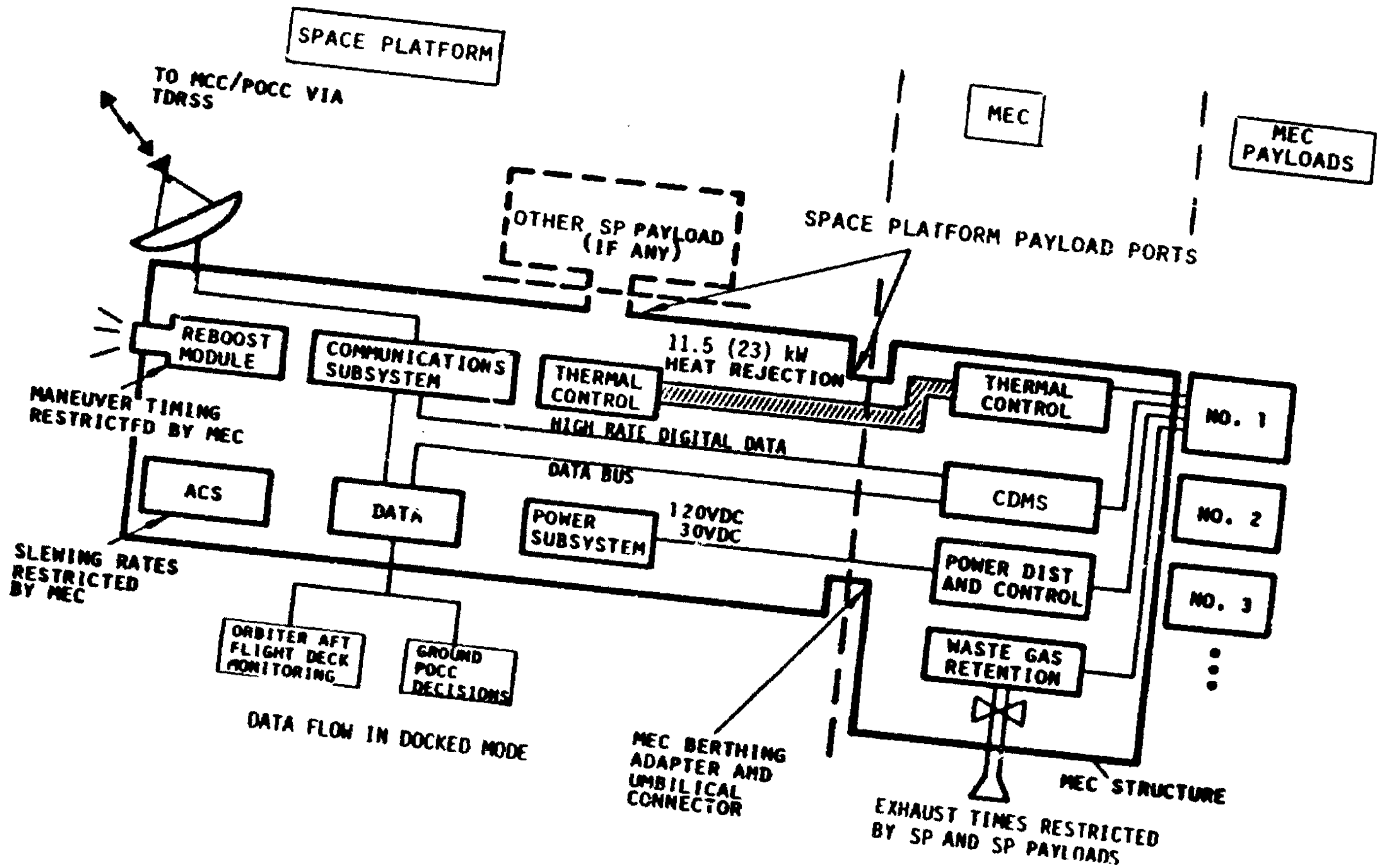

Figure 3-5. MEC/Space Platform and Related Interfaces

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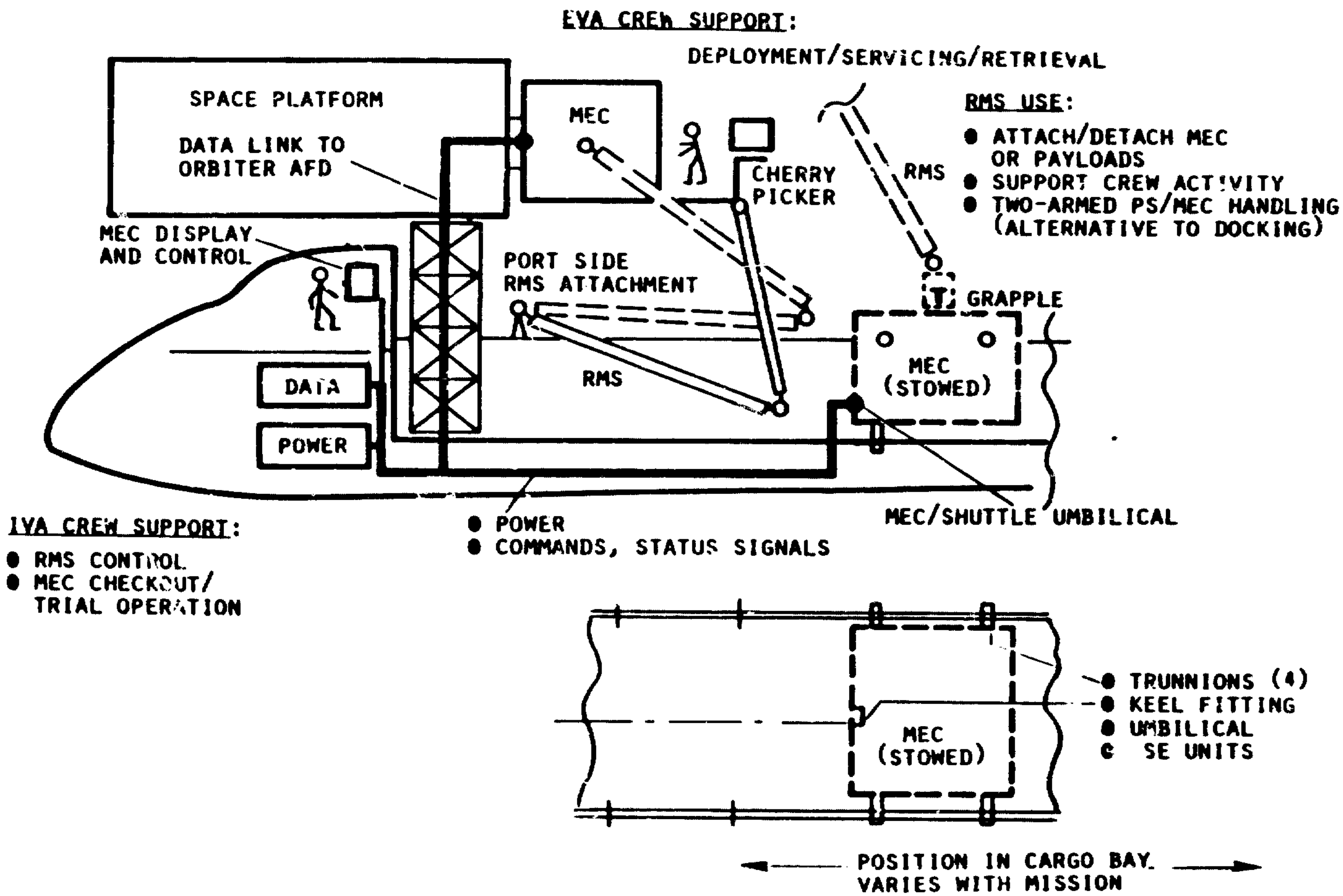


Figure 3-6. MEC Interfaces With Shuttle Orbiter and Crew

supp· ed to MEC by the initial SP or its growth version to MEC via this interface shall be 12.5 kW or 25 kW, respectively. Dead-facing of the power terminals shall be effected on the SP side of the interface. Ground terminals for each SP power bus also shall be provided through this interface.

The thermal control interface also shall be provided through the SP/MEC berthing adapter, via a fluid-loop interconnect. A payload heat exchanger on the SP side of the interface will accept up to 11.5 or 23 kW (the latter in the growth version of SP) of heat dissipated by MEC and provide heat rejection through the SP radiator.

The command/data handling interface shall be via data bus and a remote interface unit (RIU) located on the MEC side of the interface. In addition, wideband forward link (command) data and high rate digital science (telemetry) data will be directly transferred between the SP communication system and MEC. All data flow will be through appropriately shielded terminals or coax lines at the interface connector.

3.7.3 MEC Interfaces with the Orbiter, Crew and Crew System

3.7.3.1 Structural and Electrical Interfaces

MEC/Orbiter interfaces include structures and mechanisms, electrical power, and data transfer as illustrated schematically in Figure 3-6.

The MEC design shall be compatible with Orbiter cargo bay structural attachment and interface requirements as discussed in Paragraph 3.5.2.3. (See also References 10 and 14).

With MEC stowed in the Orbiter bay, electrical power and data interfaces shall be provided through an umbilical cable and a connector plate located nearby. Operating modes used in this configuration will require only modest power and data handling support by the Orbiter.

With MEC attached to SP in the docked configuration, the MEC-to-Orbiter electrical interface is established via umbilicals in the MEC/SP and SP/Orbiter berthing ports. In this configuration MEC may require Orbiter power and data handling support of several kW and several Kbps, respectively, to perform system pre-deployment checkout and verification tasks, either automatically or aided by onboard or ground-based monitoring and control. The MEC/crew system interface used in this activity will be the payload status display and control consoles located at the Orbiter cabin's aft flight deck.

3.7.3.2 RMS and Crew Interfaces

The MEC configuration shall be compatible with, and facilitate access and handling by the Shuttle Remote Manipulator System (RMS) in all phases of stowing/unstowing, transfer and SP attachment/detachment of the MEC vehicle and, similarly, of MEC payloads. The RMS end effector grapple fixture(s) shall be located in a position(s) and orientation(s) that provide convenient RMS access. The crew system interface used in RMS operations will be rotational and translational hand controllers, the RMS control computer system and software, and several closed-circuit TV cameras and monitors which augment or enhance the RMS control operator's visual perception. In situations where the payload, the grapple fixture or the attachment (berthing) structure are hidden from direct observation through the aft flight deck viewing ports, the RMS operator shall rely on CCTV signal feedback in performing his task. He also may be assisted in this task by an EVA crew member, via intercom or visual signals.

4.0 SYSTEM DESIGN

This section covers the various configuration design concepts investigated and describes the configurations selected for the initial and all-up MEC. It includes a discussion of design trades and an assessment of the selected configurations with regard to the principal design criteria established at the outset of the study. It also presents a summary of payload accommodation features and MEC system interfaces with other systems (i.e., the Space Platform, the Orbiter, ground handling and ground control) that are used in performing the MEC mission.

4.1 CONFIGURATION SELECTION CRITERIA

MEC system design requirements discussed in the preceding section are reflected in the eight key configuration criteria listed in Table 4-1. The criteria are comparable to those applied in the earlier MEC concept definition study, Part 1 (Reference 6). However, by contrast with the previous approach the new criteria include (1) the requirement for easy growth of MEC from an initial, limited-capacity to a later, full-capacity system,(2) versatility of payload accommodation, requiring support of up to seven advanced MEA-type processing facility, an advanced solidification experiment system (SES) and possibly also the EOS system if this is practical, i.e., without causing excessive design complexity.

Compactness of design to minimize Shuttle transportation cost is a matter of principal concern. This factor as well as preference for a support structure that will have been previously developed and flown on the Shuttle make the disc-shaped, 14-ft diameter, 2.5 ft thick advanced MEA design a leading contender for selection as the initial MEC configuration. The standard Spacelab pallet or a pallet-derived configuration being considered by the European Space Agency (ESA) for use as a free-flying payload carrier also is a likely configuration candidate. ESA-sponsored studies are currently in progress to adapt the Spacelab pallet for free-flying missions where it would be attached to the Space Platform. This pallet configuration also is being featured as a representative payload carrier in the recent MSFC sponsored design studies by TRW and McDonnell Douglas of the Space Platform and SASP.

Table 4-1. Configuration Selection Criteria

1. ASSURANCE OF SYSTEM SAFETY AND MISSION SUCCESS.

2. MULTIPLE PAYLOAD ACCOMMODATION AS SPECIFIED FOR INITIAL, AND ALL-UP MEC*

3. LOW COST INITIAL MEC BY WAY OF AVAILABLE STRUCTURAL ELEMENTS, SUBSYSTEM COMPONENTS AND GROUND SUPPORT EQUIPMENT.

4. EASY GROWTH TO ALL-UP MEC, E.G., THROUGH MODULAR GROWTH.

5. STS LAUNCH COST ECONOMY (WEIGHT AND LENGTH).

6. EASE OF PAYLOAD ACCESS FOR SERVICING

7. EASE OF PAYLOADS AND SUBSYSTEMS GROUND INTEGRATION AND TESTING.

8. NON-INTERFERENCE WITH OTHER SPACE PLATFORM USERS (COMPACT DESIGN)

*ACCOMMODATION OF EOS DESIRABLE BUT NOT MANDATORY. EOS MAY BE ATTACHED DIRECTLY TO SP

Ease of payload access for ground integration and/or interchange and also for possible servicing on-orbit are configuration design criteria of similar concern as in the Part I Study. In the current study phase, however, access for on-orbit servicing is not a requirement to be met by the initial MEC configuration. It will be required only for the all-up MEC configuration.

Trade studies to be discussed in Section 4.3 have addressed the question to what extent the desired evolution from the initial to the all-up MEC and commonality of design features should be taken into account in making the initial MEC configuration compatible with on-orbit servicing access on later missions.

4.2 CONFIGURATION CONCEPTS INVESTIGATED

Exploratory initial MEC design concepts investigated during this study primarily involved the following configuration types

1) Pallet-based configurations including the full pallet, half-pallet and combinations of pallet and other payload support structures.
2) MEA-C based configurations involving only minor changes from the MSFC spoked-disc design.
3) MEA-C based configurations involving major modifications from the support disc design.

Six examples of these MEC configuration families are illustrated in Figure 4-1 three of which are shown attached to the upper Space Platform payload berthing port (z-port). A set of drawings of these and other exploratory designs is included in Appendix A.

Table 4-2 lists principal features of the twelve initial MEC configurations investigated, with groups of four enclosed in each of the three categories indicated above. With few exceptions these configurations consist of payload-carrying modules connected in tandem. Berthing adapters for attachment to the Space Platform are either located to provide for in-line (tandem) attachment to the respective SP payload port or transverse attachment, e.g., in Concepts D and E. The selected initial MEC configuration, designated as concept M, is based on the MEA-C spoked disc concept with only minor changes. This configuration (see Figure 1-4) will be discussed in detail in Section 4.4.

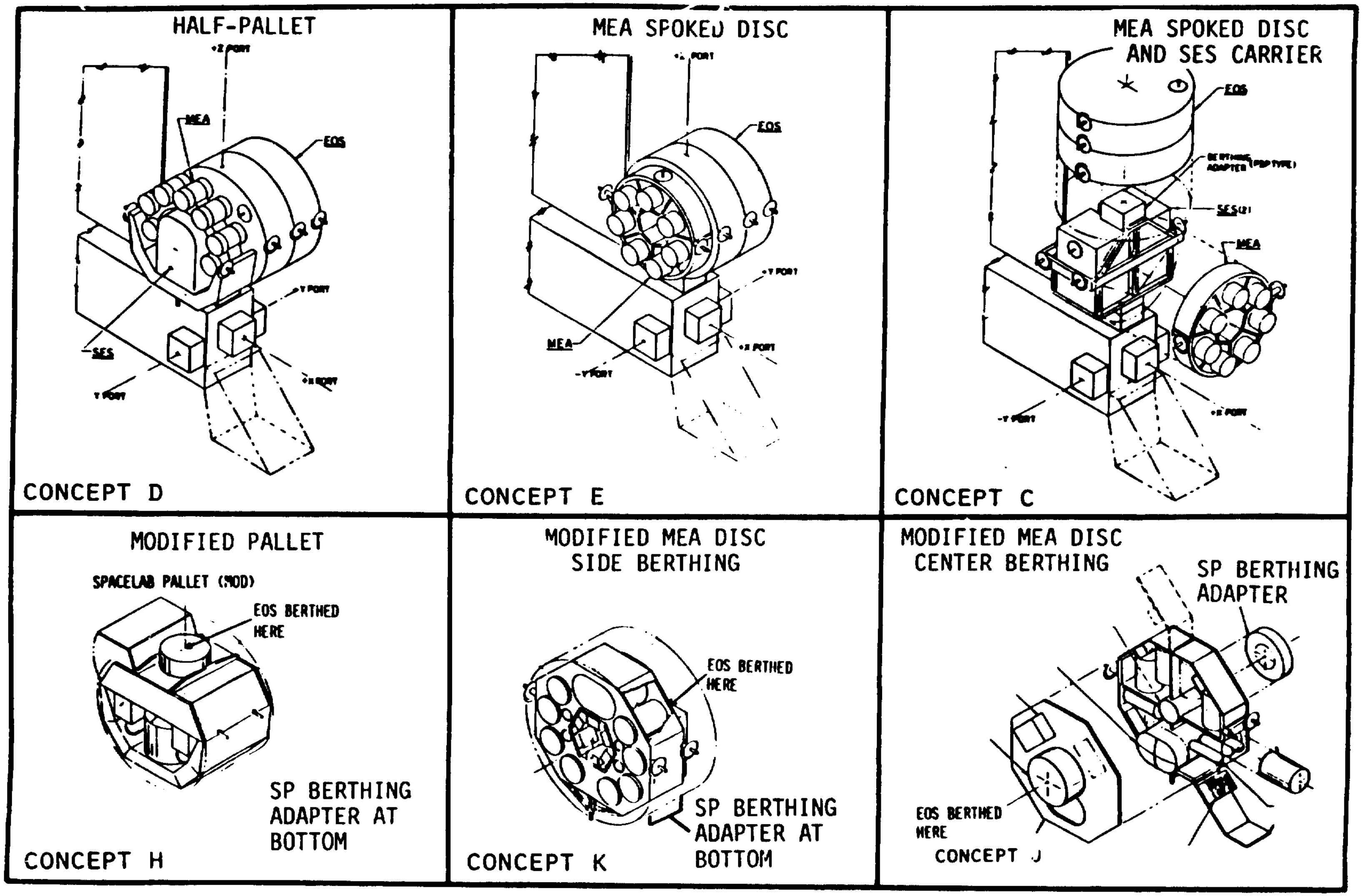


Figure 4-1. Some Exploratory Initial MEC Design Concepts

Table 4-2. Initial MEC Concepts Studied

CONFIGURATION TYPE	PALLET HALF-PALLET PALLET COMBINATION	MEA-C SPOKED DISC (W. MINOR CHANGES)	MEA-C SPOKED DISC (MODIFIED)
TRW DESIGN DESIGNATION	A, B, D, H	C, E, G, M	F, J, K, L
LOCATION OF S/P ADAPTER	PALLET BOTTOM (EXCEPT "B," FRONT FACE ADAPTER)	IN "M" ALONG CENTER LINE (OTHERS AT BOTTOM)	ALONG CENTER LINE (EXCEPT "K," AT BOTTOM)
MODULE GROUPING	IN LINE, EXCEPT "H" (CLUSTERED)	IN LINE, EXCEPT "G" (CLUSTERED)	IN LINE, EXCEPT "F" (CLUSTERED)
PAYLOADS ACCOMMODATED			
- MEA FACILITIES	4 TO 7	6 TO 7	7 TO 8
- SES	1 OR 2	1	1
- EOS	YES	YES	YES
PAYLOAD ATTACHMENT/ ACCESS	RACK MOUNTED	AXIAL	AXIAL OR LATERAL
GROWTH TO ALL-UP MEC INVESTIGATED*	(SEE NOTE)*	M	J, K, L
REMARKS	"A" IS POSSIBLE ALTERNATIVE TO "M" FOR INITIAL MEC. GROWTH TRHOUGH TANDEM ARRANGEMENT	$\boxed{\text{"M" SELECTED: MEETS ALL INITIAL MEC CRITERIA, HAS GROWTH CAPABILITY AND MEA COMMONALITY}}$	REQUIRE MAJOR MODIFICATIONS FROM MEA-C

*GROWTH CAPABILITY EXISTS IN ALL CONFIGURATIONS. DESIGN IMPLICATIONS STUDIED SPECIFICALLY ONLY IN FOUR CONFIGURATIONS LISTED

Figure 4-2 compares principal features of the MEA-C derived spoked disc concept (baseline) with the alternate concept of a standard Spacelab pallet carrying SES and seven MEA facilities mounted on a wine rack type support structure. The SES unit carried on the pallet is similar to the current S/L based SES design. That carried by the spoked disc represents a modified design which is compatible with the available mounting space in the center of the disc and a limited length dimension of 45 or 60 inches, depending on whether the unit is allowed to protrude on only one or on both sides of the 30 inch disc.

The spoked disc configuration has the programmatic advantage of providing maximum commonality between MEA-C and MEC in terms of structure and some subsystem elements.

The pallet-based configuration benefits from the use of an established primary structure previously investigated with the Shuttle Orbiter on other programs and one that will be in common use by other free-flying Space Platfrom payloads.

In both configurations the EOS would be attached in tandem to the basic MEC structure.

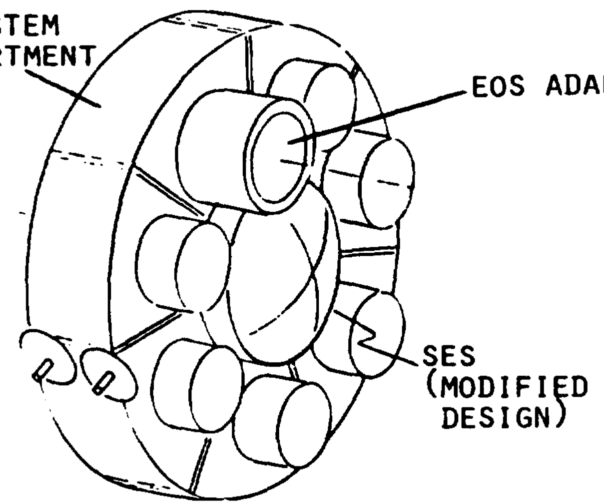
4.3 CONFIGURATION TRADES

A number of spacecraft design issues and characteristics were investigated in detail, and trade-offs performed, to aid in the selection of the preferred MEC design concept. The issues investigated include:

- Payload accommodation, attachment and access for servicing
- EOS accommodation
- Placement of berthing adapters
- Configuration of payload compartments
- Placement of MEC subsystems
- MEC payload density and transportation cost implications
- MEC Orbiter attachment provisions
- RMS reach and grapple fixture placement
- MEC evolution issues, in general

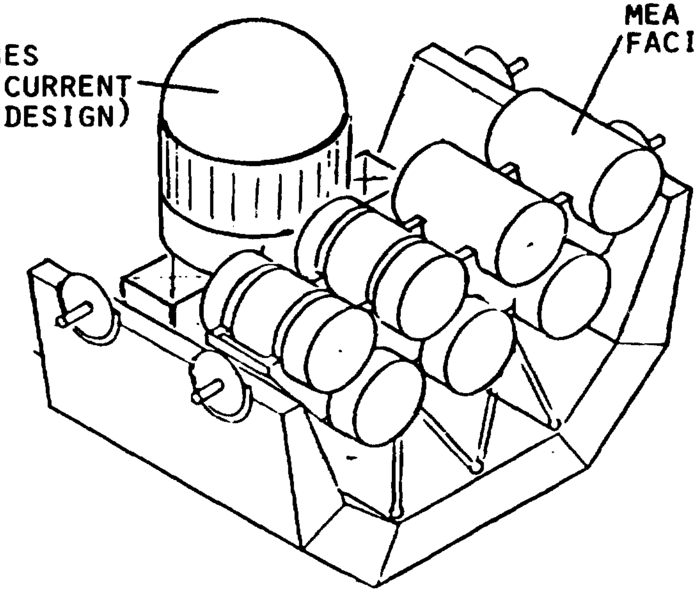
Results of these analyses are summarized in this section.

BASELINE - SPOKED DISC



- SPOKED DISC STRUCTURE (ADAPTED FROM MEA-C)
- 6 MEA FACILITIES
- SES (MODIFIED DESIGN) IN CENTER COMPARTMENT
- SUBSYSTEMS IN TRAPEZOIDAL COMPARTMENT ADJACENT TO EOS ADAPTER
- EOS ATTACHED IN TANDEM
- SP BERTHING ADAPTER IN CENTER (FAR SIDE)

ALTERNATE - S/L PALLET



- STANDARD S/L PALLET
- 7 MEA FACILITIES ON WINE RACK
- SES (CURRENT DESIGN)
- SUBSYSTEMS PARTLY IN PALLET STRUCTURE PARTLY UNDERNEATH MEA FACILITIES
- BERTHING ADAPTER AT PALLET BOTTOM
- EOS ATTACHABLE IN TANDEM

Figure 4-2. Initial MEC Configuration Alternatives

4.3.1 Payload Accommodation and Access for Servicing

The number, size and type of payloads to be carried by the initial and the all-up MEC, payload attachment geometry and access provisions for on-orbit servicing were key issues considered in MEC configuration trade studies.

Initial MEC Configuration. System design requirements call for accommodation of up to seven advanced MEA facilities contained in cylindrical canisters of, typically, 30 inch diameter and 45 inch length, and a SES unit of up to 60 inch diameter and 60 inch length. In addition, the initial and all-up MEC are to be designed for external attachment of the EOS, a cylindrical container of 14 ft maximum width and 8 ft length. (The question of whether or not it is necessary or even desirable to carry EOS as a MEC payload will be discussed below).

Regarding the Advanced-MEA spoked disc design by MSFC, the alternatives of radial and axial payload insertion were considered for MEC (see Figure 4-3). It is apparent that payload canisters of larger dimensions can be accommodated in the axial attachment mode, if they are allowed to protrude beyond one of the bulkhead planes of the 30 inch thick disc structure. The resulting increment in axial length will not be of any consequence from the standpoint of Shuttle cargo bay length dependent transportation charges since the EOS berthing adapter to be attached on the same side itself protrudes about 25 to 30 inches and thus increases the chargeable length of the vehicle.

Secondly, accommodation of the SES facility in the hub compartment of the disc also would require axial insertion and requires at least 20 to 30 inches of extra length.

Another factor favoring axial attachment and removability of payload units relates to greater accessibility for on-orbit servicing with MEC attached to the Space Platform (see Figure 1-4). The Shuttle Remote Manipulator (RMS) generally could not reach all payloads if radial insertion/removal were selected. On-orbit servicing, while not required for the initial MEC, will be a factor to be considered if that configuration is adopted as a building block (or core module) in the design of the all-up MEC.

In the all-up MEC configuration derived by adding a growth module in tandem within spoked disc (core module), the payloads carried by the growth

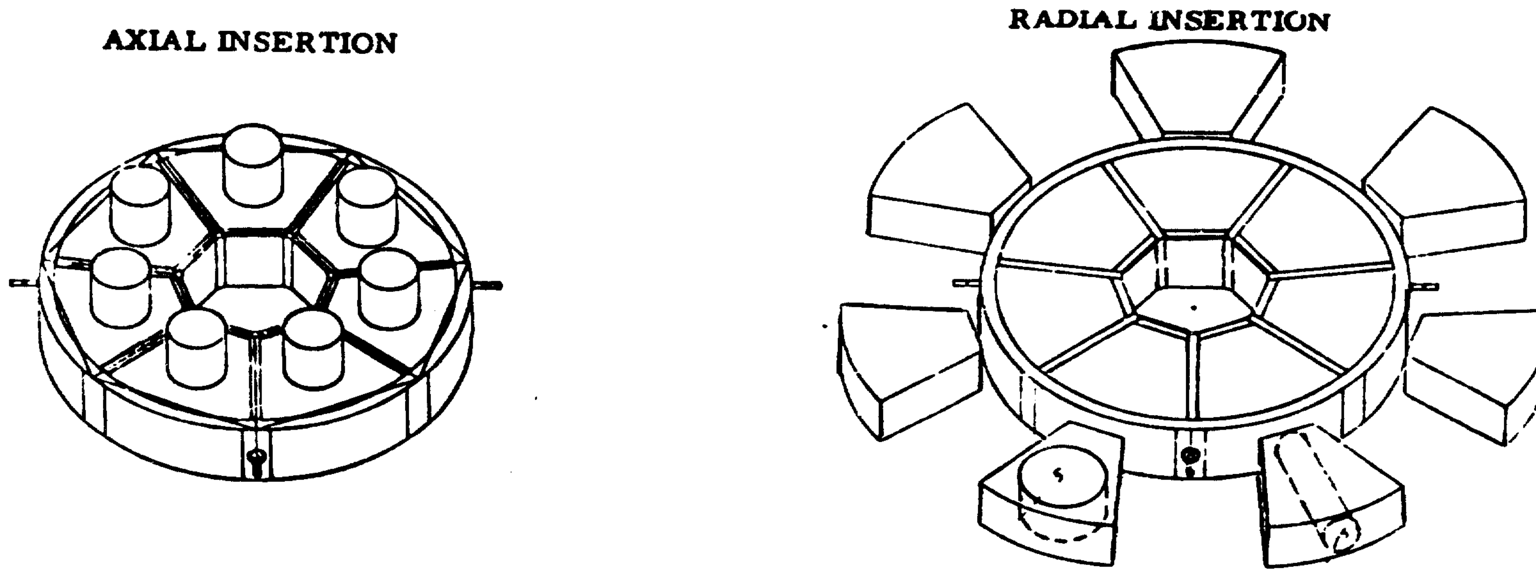


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Figure 4-3. Payload Insertion Options With Spoked Disc Configuration*

*From NASA/MSFC Advanced MEA Report, March 1981

module should be made accessible laterally by opening clam shell type compartment doors in the hull. The preferred access of these payloads for RMS handling is from two opposite sides rather than four sides to avoid interference with Space Platform appendages such as the thermal radiator extending in z-axis direction, or with payload carriers berthed on other SP payload ports.

It will be noted that in the all-up MEC configuration shown here some of the payloads (those in the disc module) are accessible axially for reasons explained above, and others (those in the growth module) laterally. Radial attachment/removal will be avoided.

The payload compartments in the spoked disc design may be made axially accessible by providing removable covers or hinged doors in one, or possibly both, bulkheads. Removable cover plates are preferable since they do not geometrically constrain the placement or dimensions of protruding payload units in the same way as hinged access doors.

To reduce structural weakening of the bulkhead the access covers should be bolted down firmly against the spokes of the disc structure, a provision that is more compatible with cover plates than with doors. Also for reasons of structural integrity, only one rather than both bulkheads should have openings.

The payload units should be attached to, and cantilevered from, support fixtures in the solid bulkhead. These fixtures also include standard electrical and fluid connector boxes with which the removable payload units are mated in the process of axial insertion.

The tie-down mechanism can be converted to provide on-orbit serviceability by using guide pins and manually operated lead screws based on a design concept developed originally for the NASA Multimission-Modular Spacecraft (MMS) and also being used on the Space Telescope and the Space Platform.

The same payload attachment/retention principle will also be applicable to the payload units of the MEC growth module which are laterally inserted.

4.3.2 Berthing Adapter Placement

Merits of different locations of the MEC-to-SP and EOS-to-MEC berthing adapters have been evaluated and preferred adapter locations defined for the selected MEC design.

In the original SP (Power Module) reference design and previous MEC concepts the berthing adapter was defined as a 5 by 5 ft square box frame mating with a similar frame on the Space Platform with the aid of four RMS end-effector type grapple fixtures. More recently, during the current design study, a new cylindrical berthing adapter envelope of 42 inch diameter and 13.5 inch length on the payload (MEC) side and 26.5 inch length on the SP side was defined by MSFC to supersede the original square envelope.

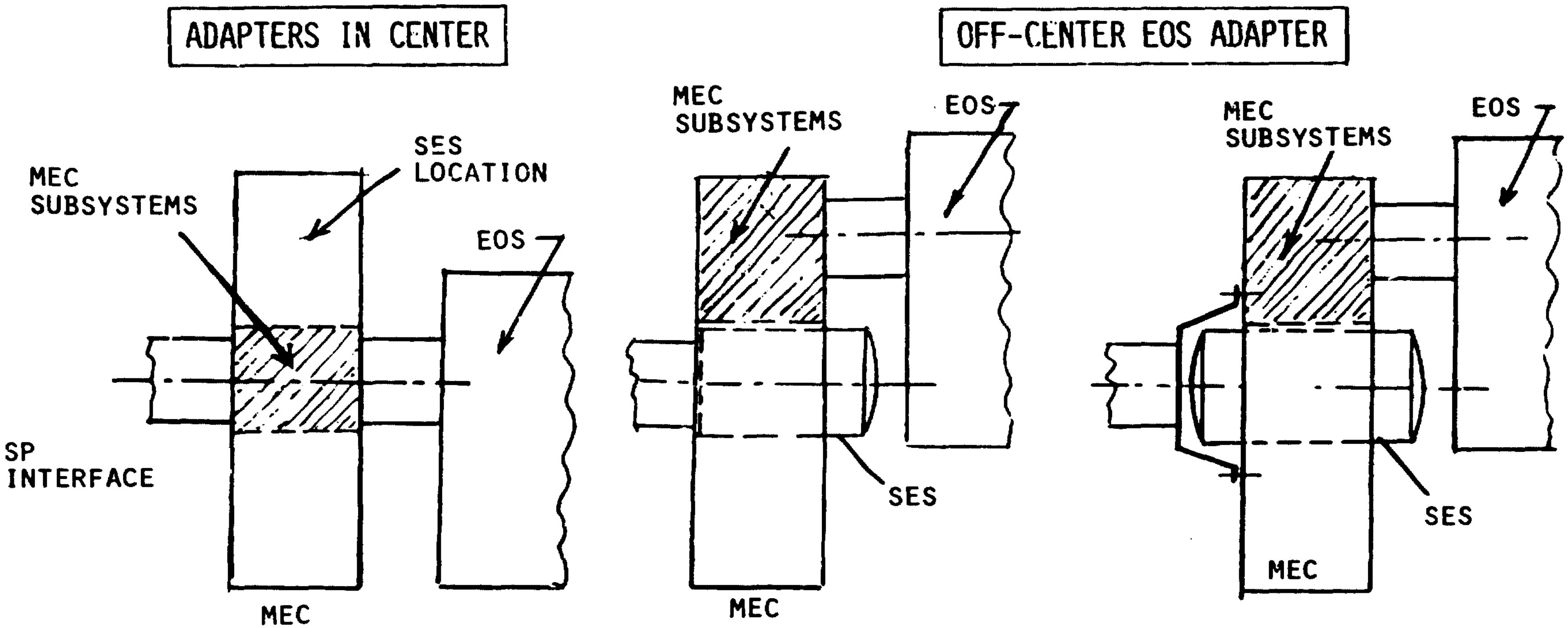
The configuration of the active and passive engagement mechanisms located in the center of the respective adapter halves has not as yet been specified. However, information provided by MSFC indicates that the adapter portion located on the SP side of the interface will be equipped with the active part, that on the payload side with the passive part of the engagement mechanism.

The adapter will probably be a standard piece of equipment supplied as GFE to any payload developed for the Space Platform.

The EOS-to-MEC adapter is assumed to be the same as the MEC-to-SP adapter since EOS will require the capability either for attachment to MEC or directly to the SP. More specifically, the SP adapter half carried by MEC will be the passive (male) portion, the EOS adapter half carried by MEC will be the active (female) portion of the pair.

The preferred attachment of the MEC and EOS combination to the SP is in line with the axis of the SP payload port used by MEC rather than in transverse direction so as to avoid interference with adjacent other payloads. Similarly an in-line (tandem) arrangement of MEC and EOS is preferred. The MEC/SP and MEC/EOS adapters therefore should be mounted on the bulkheads of the disc or drum shaped MEC configurations, or on the front and aft ends of pallet-type MEC configurations rather than at the bottom (see Figure 4-1).

With regard to adapter placement alternatives on MEC bulkheads, the three sketches shown in Figure 4-4 illustrate possible locations for the MEC/SP and EOS/MEC adapters.



- BOTH SP AND EOS ADAPTERS LOCATED IN CENTER
- SUBSYSTEMS IN CENTER COMPARTMENT
- SES REDESIGNED TO FIT INTO ONE OR TWO OFF-CENTER COMPARTMENTS

- SES IN CENTER COMPARTMENT

- EXTRA LENGTH OF SES ACCOMMODATED ON SP SIDE

- SUBSYSTEMS IN OFF-CENTER COMPARTMENT
- EOS ADAPTER OFF-CENTER NEXT TO SUBSYSTEM COMPARTMENT
- OFF-CENTER LOCATION FACILITATES EOS ROTATION ON HINGED ADAPTER FOR CORE MODULE PAYLOAD ACCESS

Figure 4-4. Adapter Placement Alternatives

The preferred SP adapter location is at the center of the left bulkhead, as dictated by clearance requirements of adjacent payloads and the SP berthing arm. Note however, that even in this centered MEC berthing arrangement a 3.5 ft long extension arm is required to clear these obstructions.

The EOS/MEC adapter is placed in an off-center position to permit SES accommodation in the large (5 ft) diameter center compartment and to facilitate on-orbit servicing of the axially attached payloads in the MEC core module when used in the all-up MEC (see below).

4.3.3 Adapter Load Analysis

Axial loads and bending moments to be transferred via the MEC/SP and EOS/MEC berthing adapters tend to be small enough so as to be of no concern structurally. Maximum loads due to angular acceleration or centrifugal effects, occur during rapid SP reorientation maneuvers. Typically, with angular accelerations smaller than 0.01 rad/sec^2 or angular rates smaller than 0.3 rad/sec and a MEC to SP center-of-mass distance of about 30 ft axial loads will not exceed 0.01g, corresponding to 300 lb of tension for a 30,000 lb maximum MEC weight. Under the same conditions, and with an adapter to MEC center-of-mass distance of 10 ft, the maximum bending moment acting on the adapter flange will be of the order of 3,000 ft lb. Thus, assuming a 3 ft diameter of the adapter flange, the maximum flange load due to this bending moment would be less than 2,000 lb. The axial tension exerted by the adapter locking mechanism is estimated to be at least 5 times larger.

These results are preliminary. A more detailed analysis of loads vis-a-vis adapter load transfer capabilities must be deferred until the SP adapter structure and mechanism design characteristics will become available.

4.3.4 Spacelab Pallet Utilization

The Spacelab pallet might be used as a carrier structure that will be available in the mid 80's for accommodation of Space Platform space science and applications type payloads including materials processing payloads. Use of the pallet as MEC carrier (starting in 1987 or 88) would have the potential advantage of:

- Having been previously flight proven on Shuttle/Spacelab missions
- Having been adapted for use in the free-flying mode by various other Space Platform payloads
- Providing payload support subsystems with characteristics that may be suitable for utilization by MEC
- Being a general purpose carrier not assigned exclusively for use by the MEC project and thus possibly resulting in some cost savings

Adverse factors inherent in pallet utilization by MEC include the following:

- The pallet, with an estimated weight of about 2,200 lb, would require the addition of a secondary structure to support MEC payloads and subsystems, resulting in a significant weight penalty compared with a dedicated MEC carrier.
- Cargo bay utilization is inefficient for MEC purposes, with nearly 12 ft length for the pallet vs. only 5 ft for the MEA type disc configuration, taking into account SP and EOS berthing adapters in both cases (see Section 4.4).
- Also, the primary and secondary structures used for payload support leave only about 60 percent of the cylindrical cargo bay volume occupied by the pallet for use by the payload, and at least one third of this space remains unusable.

The weight and volume penalties associated with use of the pallet are estimated to result in an increase in Shuttle launch cost by up to $3 million compared with the disc shaped initial MEC configuration. The cost difference for all-up MEC missions which would require the addition of a second pallet are expected to be approximately twice as large (see also the discussion of transportation costs in Section 6.6).

Regarding the feasibility of pallet adaptation for use as MEC carrier, a concurrent study being performed by ERNO (Bremen, Germany) under ESA contract will determine modification requirements, payload accommodation capabilities, subsystem support capabilities, and will provide weight and cost estimates. The objectives, scope and schedule of this study (to be concluded in March 1982) and preliminary data regarding pallet suitability for MEC use are summarized in Tables 4-3 and 4-4. With the completion of the ERNO study projected about three months after completion of this MEC study phase the merits of the pallet as potential MEC carrier cannot be fully assessed and requires further study. This applies especially to the potential use of pallet subsystems or subsystem elements (see also Section 5).

Table 4-3. Spacelab Follow-On Development ERNO Medium-Term Study

ESA	RFQ 3-4014-81-F	PALLET SYSTEM STUDY	PART A
ESA	RFQ 3-4015/81/F	MODULE STUDY	PART B

OBJECTIVE: ENGINEERING AND PROGRAMMATIC EVOLUTION OF A RANGE OF APPLICATIONS TO PREPARE FOR A SPACELAB FOLLOW-ON PROGRAM

STUDY DURATION: ABOUT 7 MONTHS: SEPTEMBER 1981 THROUGH MARCH 1982

GENERAL GUIDELINES:

- LONG DURATION MISSIONS WITH COMMENSURATE SAFETY AND RELIABILITY SPECS
- COMMONALITY OF SPACELAB AND SPACE PLATFORM EQUIPMENT
- EMPHASIS ON EUROPEAN HARDWARE PROCUREMENT
- ON-ORBIT SERVICING
- COMPATIBLE WITH POWER SYSTEM (12 AND 25 kW VERSIONS)
- EMPHASIS ON NEAR-TERM SOLUTIONS FOR ENGINEERING TRADES

STUDY TASKS:

1. REQUIREMENTS REVIEW
2. CONCEPTUAL TRADES, OPERABILITY ANALYSIS AND EVALUATION
3. PRELIMINARY DESIGN (STRUCTURE, MECHANISMS, SUBSYSTEMS)
4. SYSTEM LEVEL SYNTHESIS AND PROGRAMMATICS

Table 4-4. Spacelab Pallet Issues

ISSUE	ERNO COMMENT AS OF OCTOBER 1981
I. PALLET STRUCTURE AND SUBSYSTEMS CAPABILITY	
• COMPATIBILITY OF PALLET WITH MPS PAYLOAD REQUIREMENTS	GOOD POTENTIAL. NO PROBLEMS IDENTIFIED. PRELIMINARY DATA PROVIDED
• PALLET STRUCTURAL INTEGRITY FOR LONG DURATION MISSIONS ATTACHED TO THE SPACE PLATFORM	NO PROBLEMS IDENTIFIED UNDER STUDY
• PALLET SUBSYSTEMS CAPABILITY TO SUPPORT MEC MISSIONS	UNDER STUDY. PRELIMINARY BLOCK DIAGRAMS PROVIDED FOR CDMS, TC, POWER
• PALLET GROWTH POTENTIAL	NO INVESTIGATIONS PRESENTLY PLANNED EXCEPT FOR REMOUNTING THE SUBSYSTEMS
II. PALLET-SPACE PLATFORM (SP) INTERFACES	
• INTERFACE REQUIREMENTS	QUALITATIVE STATEMENTS DERIVED, SOME QUANTITATIVE VALUES GENERATED
• INTERFACE DESIGN FEATURES	UNDER STUDY
• MODS TO PALLET TO MEET INTERFACE REQUIREMENTS	UNDER STUDY, PRELIMINARY DATA PROVIDED
III. PALLET DEVELOPMENT SCHEDULE AND COST DATA	
• PALLET MODIFICATION COST FOR ATTACHMENT TO SP	DATA AVAILABLE IN MARCH 1982
• DEVELOPMENT SCHEDULE TO MODIFY PALLET	DATA AVAILABLE IN MARCH 1982

(REFERENCE: ERNO TO TRW DOCUMENT: USE OF SPACELAB PALLET AS A CANDIDATE MEC, 9 OCTOBER 1981)

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4.3.5 EOS Integration With MEC

Mission plans call for two modes of EOS operation

(a) As a payload directly attached to the SP, without requiring MEC support as illustrated in Figure 4-5.

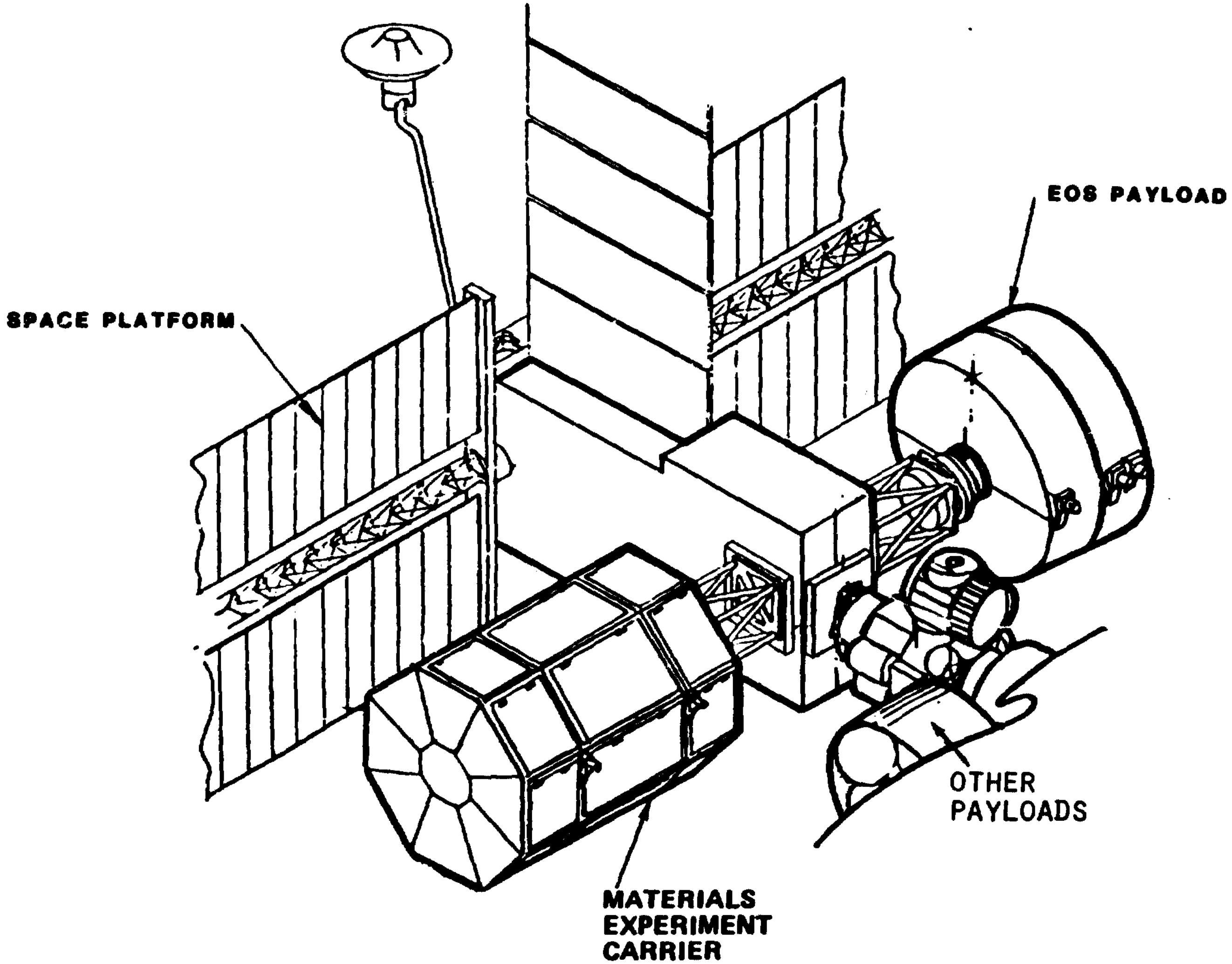
(b) As a payload integrated with MEC, being supported by MEC subsystems and not interfacing directly with the SP as host vehicle.

This dual mode capability permits the EOS mission to continue independent of MEC mission durations, i.e., regardless of whether MEC is removed for refurbishment on the ground (mode a). If MEC is present as a SP payload, EOS integration with MEC (mode b) establishes a single interface with the SP and avoids occupancy of two payload ports out of a total of three or four*, thus leaving more ports available for other SP users. The overall objective is to gain greater operational flexibility in the use of the Space Platform by EOS, MEC and other payloads.

Results of the Space Science and Applications Platform (SASP) study performed by TRW, Reference 15, illustrate the high demand for SP payload accommodation space which justifies the added complexity of MEC/EOS integration in mode b. Of 70 potential candidate SP payloads identified in the SASP study the large majority require less than 3 kW power and 20 require less than 2 kW. These payloads may be operated simultaneously with MEC and EOS, or in a time-sharing mode if the power provided by the Space Platform is insufficient. In many instances SASP payloads would preferably be accommodated intermittently, using an available extra berthing port, rather than experiencing a long deferment in accommodation. An additional benefit resulting from having an extra berthing port available for other SP users is the more effective utilization of Shuttle payload delivery capabilities during the periodic (semi-annual) SP revisits.

These benefits must be weighed against the added complexity of MEC and EOS interface design and MEC deployment, retrieval and servicing operations introduced by the MEC/EOS integration requirement. System design and cost implications are summarized in Table 4-5. Most of the items identified are expected to have a minor cost impact or do not affect cost at all. Two items identified as having a medium cost impact involve greater thermal con-

*The total number of available SP payload ports has not been firmly defined by MSFC at this writing



MEC AND EOS CAN OPERATE ON THE SPACE PLATFORM ON SEPARATE DOCKING PORTS IF MISSION PLANNING SO DICTATES.

Figure 4-5. Space Platform With MEC and EOS Docked on Y-Ports

Table 4-5. Cost Impact of Adding EOS to Initial MEC

ITEM	COST IMPACT
STRUCTURE	
BEEF-UP FOR EOS BERTHING ADAPTER	MINOR
VOLUME FOR ROUTED UTILITIES	MINOR
THERMAL	
LARGE FLOW RATE, LOW ΔT (ADDED PUMP)	MEDIUM
OTHER SUBSYSTEMS	
ADDS ONE MORE PAYLOAD FOR TOTAL OF 8	MINOR
INTEGRATION AND TEST	
ADDS AN EOS SIMULATOR	MEDIUM
PAYLOAD INTEGRATION	
ADDS TO MEC INTEGRATED TEST SCHEDULE	MINOR
OPERATIONS	
INCREASES SP ACCESSIBILITY TO USERS	N/A
MEC EVOLUTION	
ACHIEVES EARLY COMMERCIAL CAPABILITY FOR MEC	N/A

trol complexity (due to the low temperature range of EOS processing) and added integration and test operations involved in using an EOS ground simulator to verify MEC/EOS compatibility and interface functions.

Without having actual cost data at this time it appears that the programmatic and SP operational benefits achievable by MEC/EOS integration in mode b outweigh the added complexity imposed on MEC system development, test and mission operations.

4.3.6 MEC Module Arrangement Issues

Evolution to all-up MEC will require primarily an increase in payload accommodation capacity. The preferred approach is to add a growth module to the initial MEC which, by preserving its basic subsystems and payload accommodation capability, then becomes the "core" module of the all-up MEC.

Secondly, the development of payloads servicing capability from the initial MEC (which does not have to provide this capability) will be required. The impact of this requirement on the design and arrangement of the core and growth modules can be summarized as follows:

1. By utilizing the initial MEC as core module a part of the payloads accommodated in the all-up MEC will be of limited size, comparable to MEA facilities. Such payloads will probably be of exploratory design, requiring only short mission durations.
2. MEC missions durations will initially be 6 months, but will ultimately evolve to 12 months or more. At least the exploratory type of payloads may have to be exchanged at 6-month intervals. Consequently, the core module will require conversion to serviceability.
3. Core module conversion will be feasible if the initial design makes appropriate provisions for payload attachment/removal on orbit.
4. Axial payload attachment was previously shown to be advantageous on the initial MEC. With this design feature retained in the core module, it will be necessary to arrange the core module at the aft end of the all-up MEC. The growth module, placed between the SP berthing port and the core module, will therefore require side access to its payload compartments.
5. With this arrangement and the MEC subsystems still housed in the core module, it will be necessary to carry power and signal cables and coolant lines through the growth module into the core module resulting in a small weight penatly.

Alternative module arrangements were considered. However, they did not permit retention of the initial MEC as core module, or did not give access to core module payloads for servicing, or did not retain the subsystem

location in the core module, a major cost saving consideration in MEC evolution.

The result of applying the above design logic is reflected in the selected MEC configuration presented in Sections 4.4.2 and 4.4.3.

4.4 SELECTED MEC CONFIGURATION

4.4.1 Selected Concept

The various exploratory design concepts discussed in Section 4.2, and shown in greater detail in Appendix A, were presented to MSFC in a meeting held at the midpoint of the study, in August 1981, see Reference 16. As a result of this meeting TRW was directed by the MEC Project Office at MSFC to adopt the design concept to be described in this section (see Reference 17 letter by Mr. Ken Taylor, dated 23 September 1981).

The selected initial MEC concept is based on adaptation of the Advanced MEA spoked disc support structure and subsystem design (see Table 4-6). The payloads are attached axially through access doors or openings in one bulkhead. This permits larger payload units to be accommodated than by radial insertion.

An alternative design is based on adaptation of the standard Spacelab pallet.

Growth to the all-up MEC configuration is achieved through addition of a four-compartment, side-loaded, drum-shaped add-on module that is attached to the disc-shaped MEC core module. Subsystems located in the core module are retained with extension of capability, as required, to support the added payloads.

In the case of the pallet based MEC design, growth to the all-up version could be achieved by addition of a second pallet in tandem with the first.

4.4.2 Initial MEC Configuration

The "decision tree" Figure 4-6 shows the steps followed in arriving at the selected configuration and payload arrangement for the initial MEC, based on the MEA spoked disc design. The rationale for each decision is indicated in the column on the right hand side of the chart. The decision in item 6 to use an off-center location for the EOS berthing adapter is influenced in part by payload access requirements as indicated at the bottom of the corresponding decision tree for the all-up MEC configuration.

Table 4-6. Selected Concept

INITIAL MEC	BASELINE: MEA-C SPOKED DISC • SEVEN TRAPEZOIDAL COMPARTMENTS. P/L'S AXIALLY LOADED • SUBSYSTEMS IN ONE SUCH COMPARTMENT • CENTER COMPARTMENT HOUSES SES • EOS ADDED IN TANDEM, AFT END • BERTHING ADAPTERS ADDED, BOTH SIDES ALTERNATIVE: S/L PALLET • SES CURRENT DESIGN, SUPPORT STRUCTURE • SIX MEA PAYLOADS ON WINE RACK STRUCTURE • SUBSYSTEMS MODIFIED FOR MEC • EOS ATTACHED IN TANDEM
ALL-UP MEC	CORE MODULE (INITIAL MEC SPOKED DISC) • EXPANDED S/S CAPABILITIES • COMPARTMENTS USED FOR SMALL SIZE (E.G., EARLY EXPERIMENTAL) PAYLOADS GROWTH MODULE • 4 COMPARTMENTS FOR LARGE (4.5 FT DIAM.) PAYLOADS, SIDE LOADED. MEC B CONFIGURATION FROM MEC STUDY, PART 1 • CORE MODULE AT AFT END OF GROWTH MODULE • EOS ATTACHED IN TANDEM

ISSUE	RATIONALE
1. Baseline config.	● MEA commonality (pallet is secondary choice)
2. Payload attachment	● More space for large payloads (protrusion)
3. Subsystem placement	● Center compartment used for SES
4. SP adapter	● Facilitates tandem arrangement SP-MEC-EOS (clearance of SP stay-out volumes) ● Clearance of SP stayout volumes ● Clearance of SP stayout volumes
5. EOS accommodation	● Conserves SP ports ● Simplifies interface
6. EOS Attachment	● Center obstructed by SES ● See also item 6 on p. 53

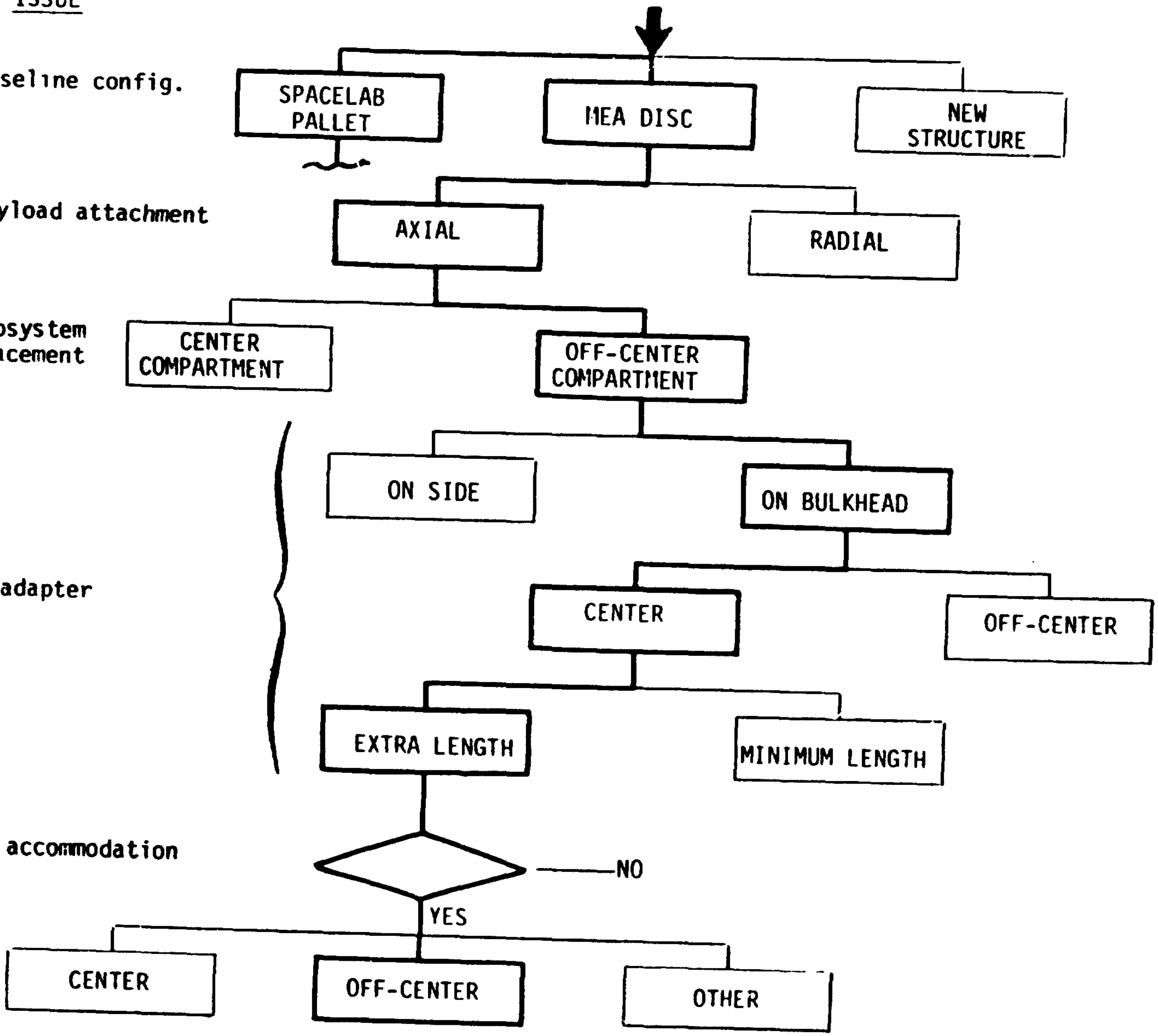


Figure 4-6. Initial MEC Configuration Logic Flow

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Figure 4-7 shows the initial MEC configuration in outline, with EOS attached. Figure 4-8 shows an exploded view of MEC and EOS in the alignment used for berthing to the Space Platform aft payload port (+x port). This illustration also shows two other payload ports (+z and -y ports) to which the MEC/EOS might be attached, assuming that four such ports are available on the Space Platform. (Note that availability of the z-port is not assured at this time, particularly in the initial 12.5 kW SP configuration). Six MEA-C type cylindrical payloads of equal size are shown protruding from the peripheral compartments of the MEC disc structure, while SES occupies the center compartment. One peripheral compartment, i.e., that located adjacent to the EOS berthing adapter, is used to house the MEC subsystems. Reasons for the off-center location of this adapter were previously discussed in Section 4.3.2.

A spoked disc configuration with a flat-sided (prismatic) rather than a cylindrical hull was considered as an alternative. The two concepts are compared in Figure 4-9. While the flat-sided shape may save some manufacturing cost it also, in effect, reduces the available payload compartment volume, and particularly, that of cylindrical payload containers. Another alternative with flat sides (not shown here) would minimize this deficiency by placing the edges half-way between, rather than at the spokes.

Figure 4-10 shows the diversity of payload sizes and shapes that can be accomodated on the spoked disc support structure by axial attachment. The 26 inch long cylindrical adapter (shown at the top) that is used to connect EOS to MEC demarcates a slice of orbiter cargo bay volume which is chargeable to the MEC program regardless of whether it is used or not used for payload mounting. Therefore, any payloads that protrude up to about 20 inches outside the spoked disc bulkhead can be accommodated without adding to the transportation cost if this cost should turn out to be volume-dependent (length dependent), see also Section 6.6.

4.4.3 All-Up MEC Configuration

The decision tree, Figure 4-11, is a counterpart of that shown in Figure 4-6 for the initial MEC configuration and involves interrelated issues. E.g., retention of the initial MEC as core module for the all-up MEC reflects in subsystem placement (issue 2) and in access provisions for the core module payloads for on-orbit servicing (issue 6). Note that the

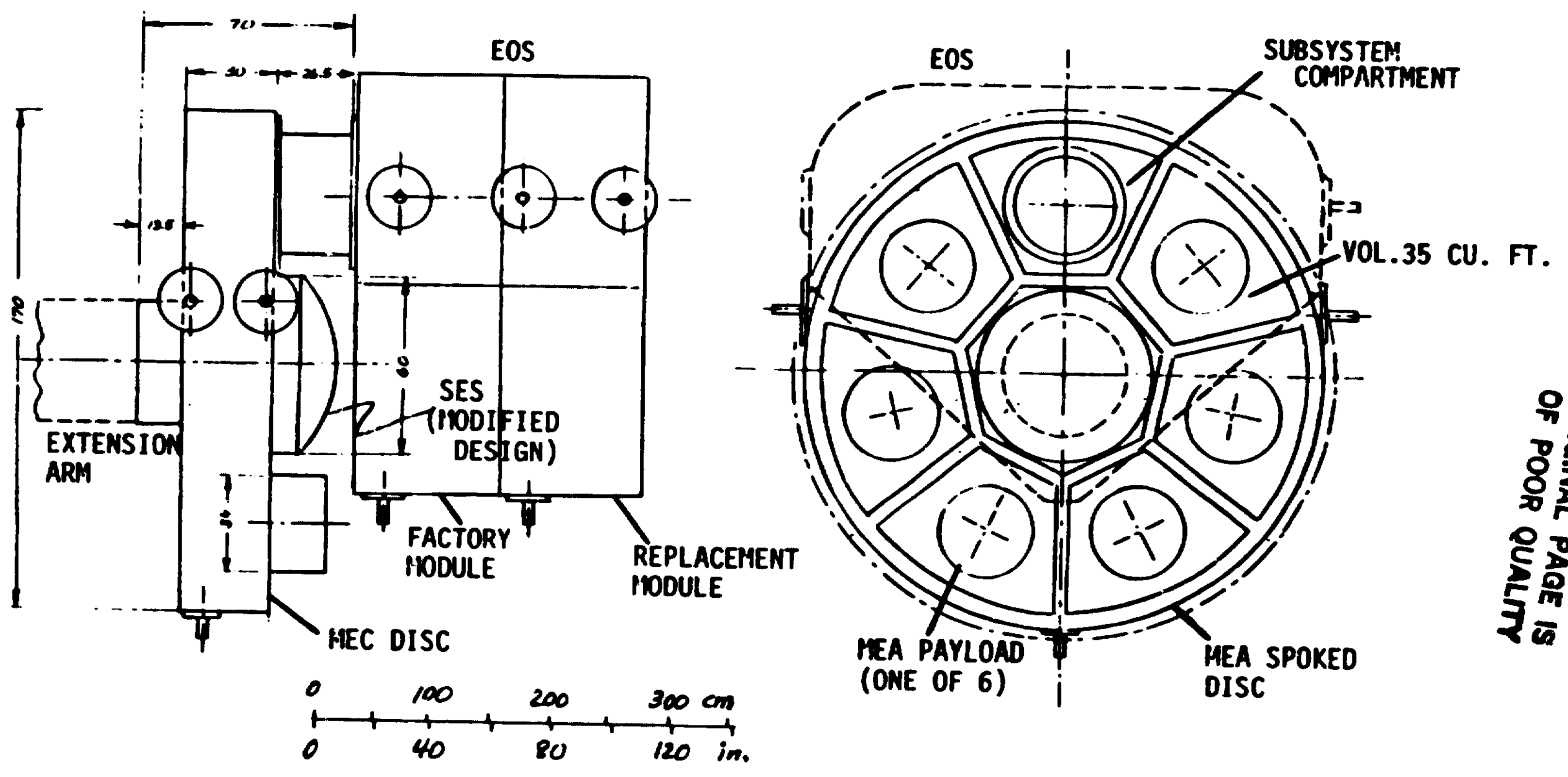


Figure 4-7. Initial MEC Configuration, Including EOS

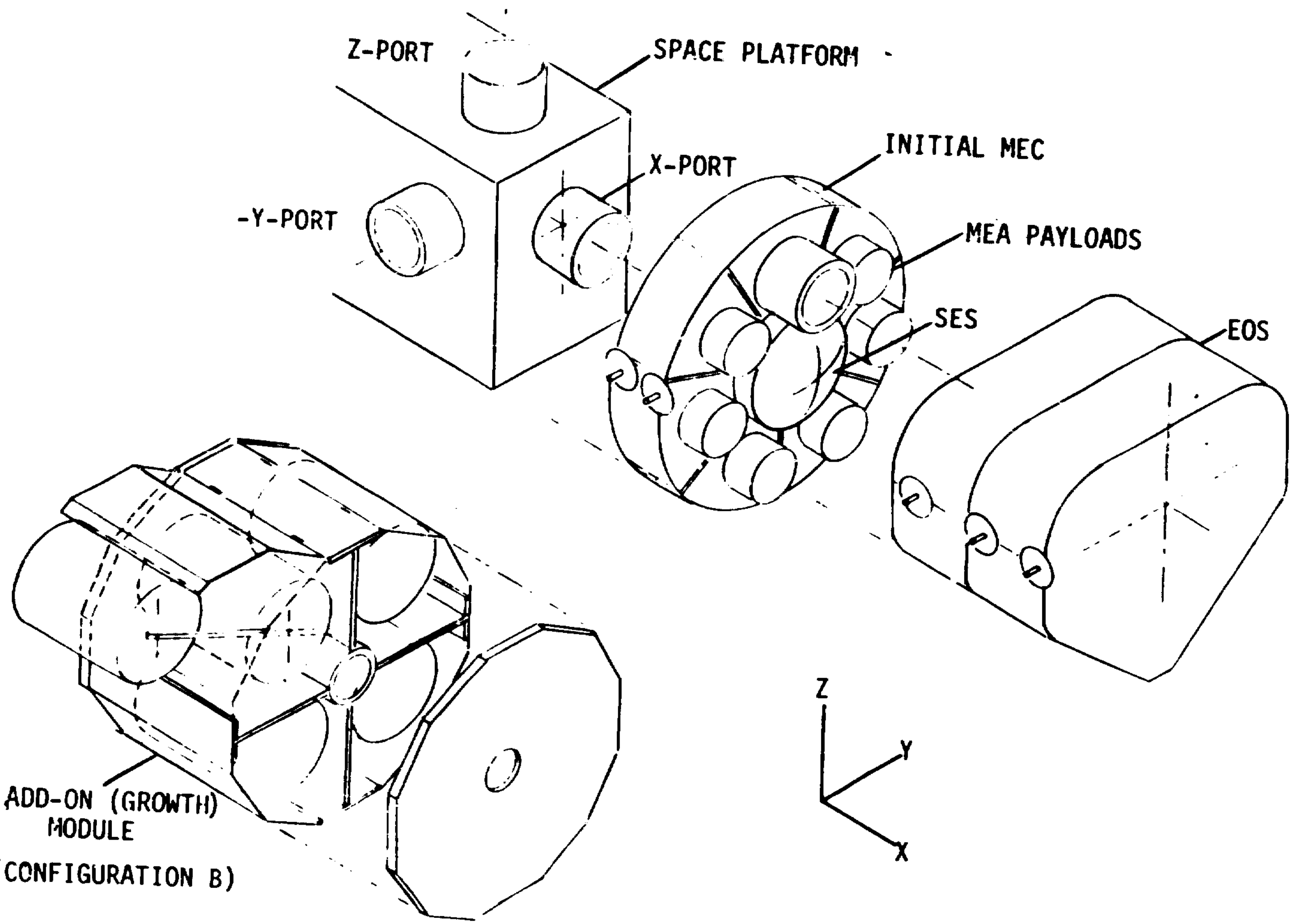
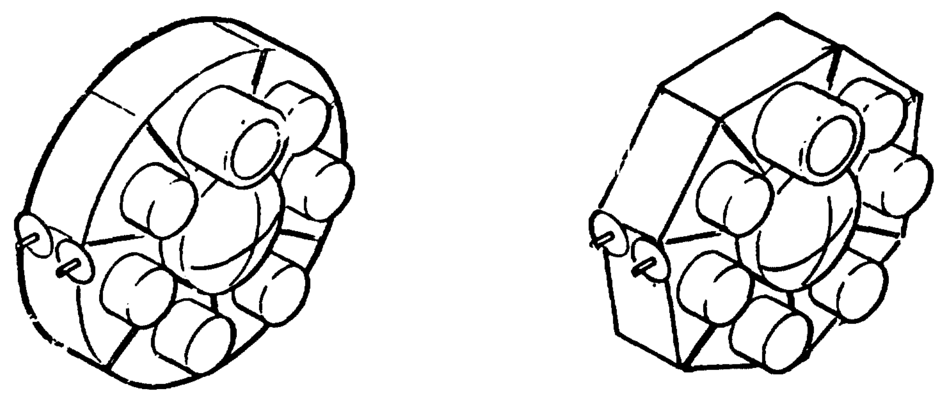
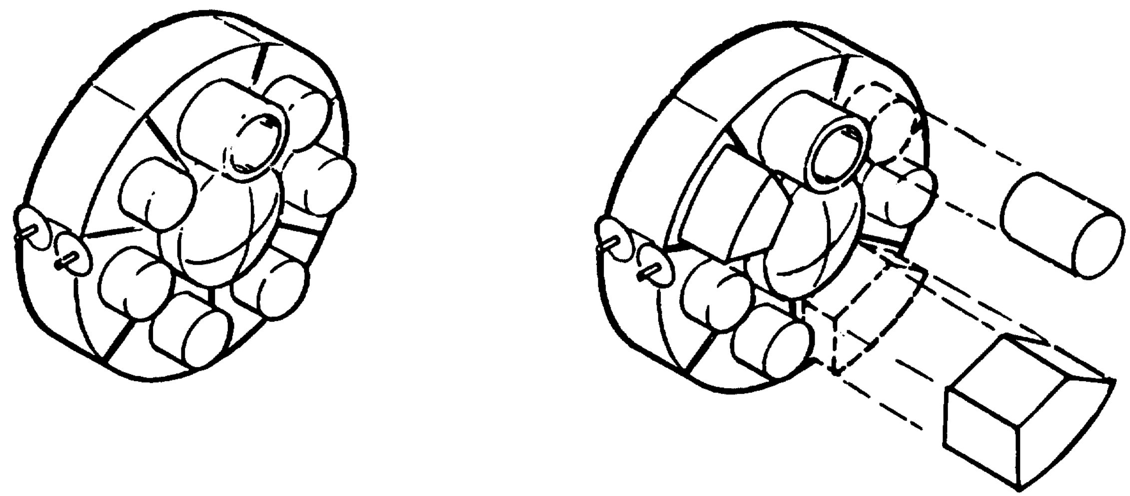


Figure 4-8. Initial MEC (Spoked Disc) Configuration and Add-On Growth Module



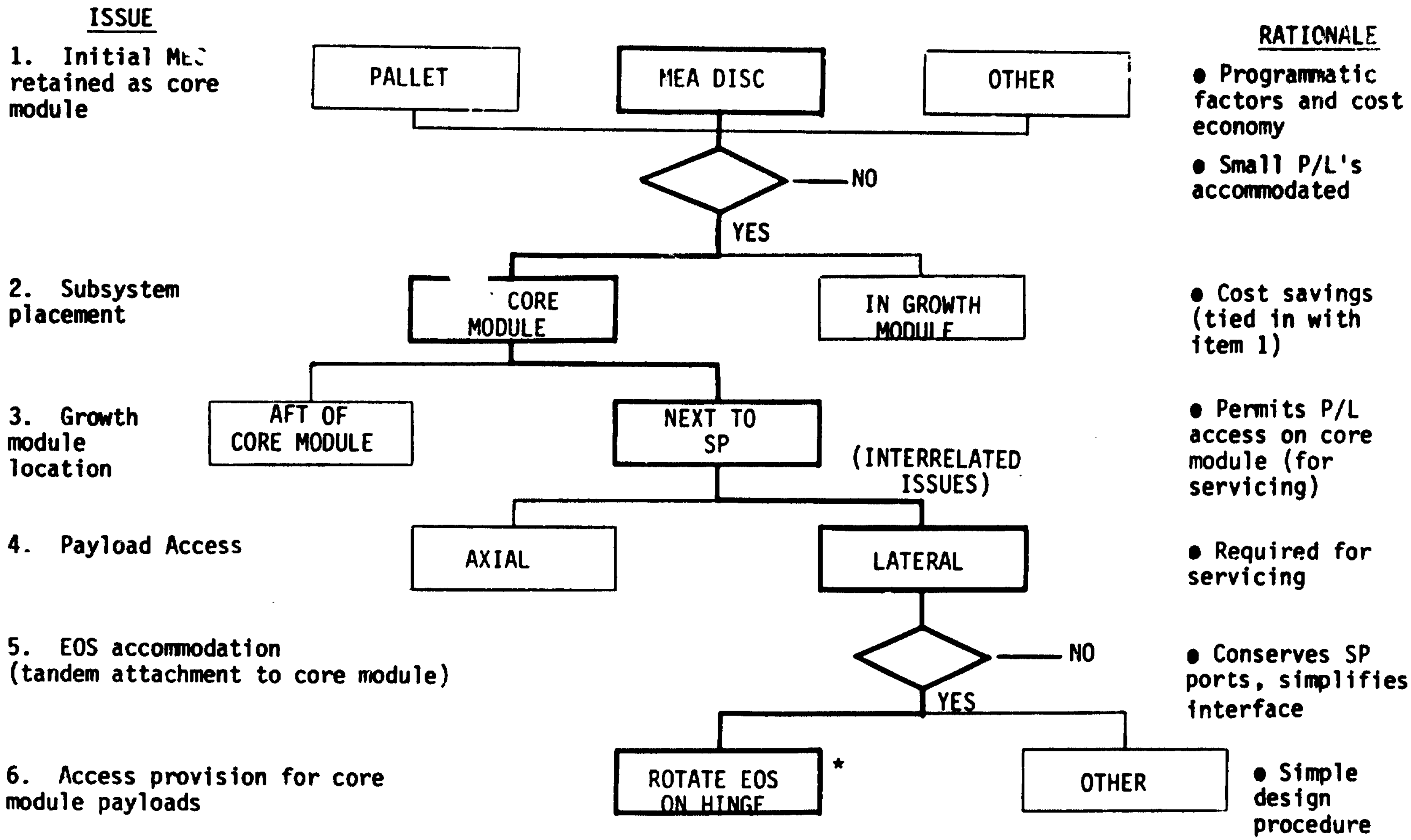
- CYLINDRICAL HULL ADOPTED FOR MEC, SAME AS IN ADVANCED MEA
- SEVEN-SIDED PRISMATIC HULL MAY SAVE SOME MFG. COST BUT RESULTS IN COMPARTMENT VOLUME REDUCTION BY 8 PERCENT. MAXIMUM DIAMETER OF CYLINDRICAL PAYLOAD UNITS REDUCED TO 38 INCHES (16 PERCENT), VOLUME REDUCTION ABOUT 30 PERCENT
- ALTERNATIVE CONFIGURATION: EDGES AT COMPARTMENT CENTERS, SIDES STRADDLING SPOKES. MAXIMUM PAYLOAD DIAMETER NEARLY SAME AS FOR CYLINDRICAL HULL

Figure 4-9. Spoked Disc Alternatives



- AXIAL ATTACHMENT PERMITS PROTRUSION OF PAYLOAD UNITS. INCREASES MAXIMUM VOLUME CAPACITY BY 80 PERCENT
- CYLINDRICAL CONTAINERS FOR PRESSURIZED PAYLOAD UNITS
- UNPRESSURIZED TRAPEZOIDAL CONTAINER BOXES PROVIDE PAYLOAD VOLUME INCREASE BY 26 PERCENT
- IMPACT OF COVER PLATE CHANGE ON DISC STRUCTURAL CHARACTERISTICS (ESP. REDUCTION IN NATURAL FREQUENCY)
- PLACEMENT OF HEAVY PAYLOADS PREFERABLY IN UPPER COMPARTMENTS TO KEEP MEC C.G. NEAR SILL TRUNNION ELEVATION

Figure 4-10. Payload Accommodation Diversity



*A factor in selecting eccentric EOS attachment to core module (item 6 on p. 49)

Figure 4-11. All-Up MEC Configuration Logic Flow

decisions in issues 3 and 4 are interrelated with each other and with issue 6, all involving payload access on orbit. On-orbit serviceability of payloads in the all-up MEC permits long mission durations for some of the payloads, e.g., those carried by the add-on growth module, without requiring the same orbital stay time for others.

As shown in the configuration drawing, Figure 4-12, the four-payload growth module is attached at the forward bulkhead of the six-payload core module. As in the initial MEC configuration, EOS is again attached to an off-center berthing adapter placed adjacent to the trapezoidal compartment of the core model that houses the MEC subsystems. With the growth of subsystem capacity and size required to support the all-up MEC system, a second trapezoidal compartment will be dedicated to housing subsystems and other support equipment, e.g., a waste retention tank. Hence, the reduction of core module payload capacity by one unit.

A utility tunnel, shown in the center of growth module cross section, on the right, is used to connect power and signal conduits and coolant lines from the SP berthing adapter to the MEC subsystem compartments, and vice versa.

Some extra length of power cables (7 ft), signal cables and fluid lines (14 ft) is unavoidable with the selected design approach, which caters to the servicing access objective for payloads carried by the core module.

Another design feature keyed to this objective is the provision for moving the EOS assembly out of the way to allow access to core module payloads. As shown in the MEC side view drawing, this is accomplished by a hinge in the EOS berthing adapter. Design details of this feature still require further definition. The preliminary concept shown here assumes that the retention mechanism in the active half of the adapter carried by MEC will be released prior to flip-up, with flexible cables and fluid lines having enough slack to permit the desired hinge rotation. This would avoid having to disengage the electrical and fluid connectors at the MEC/EOS interface. Several alternative designs have been investigated that similarly do not require modification of the passive adapter half carried by EOS. I.e., the extra cost of interface modification needed to provide core module

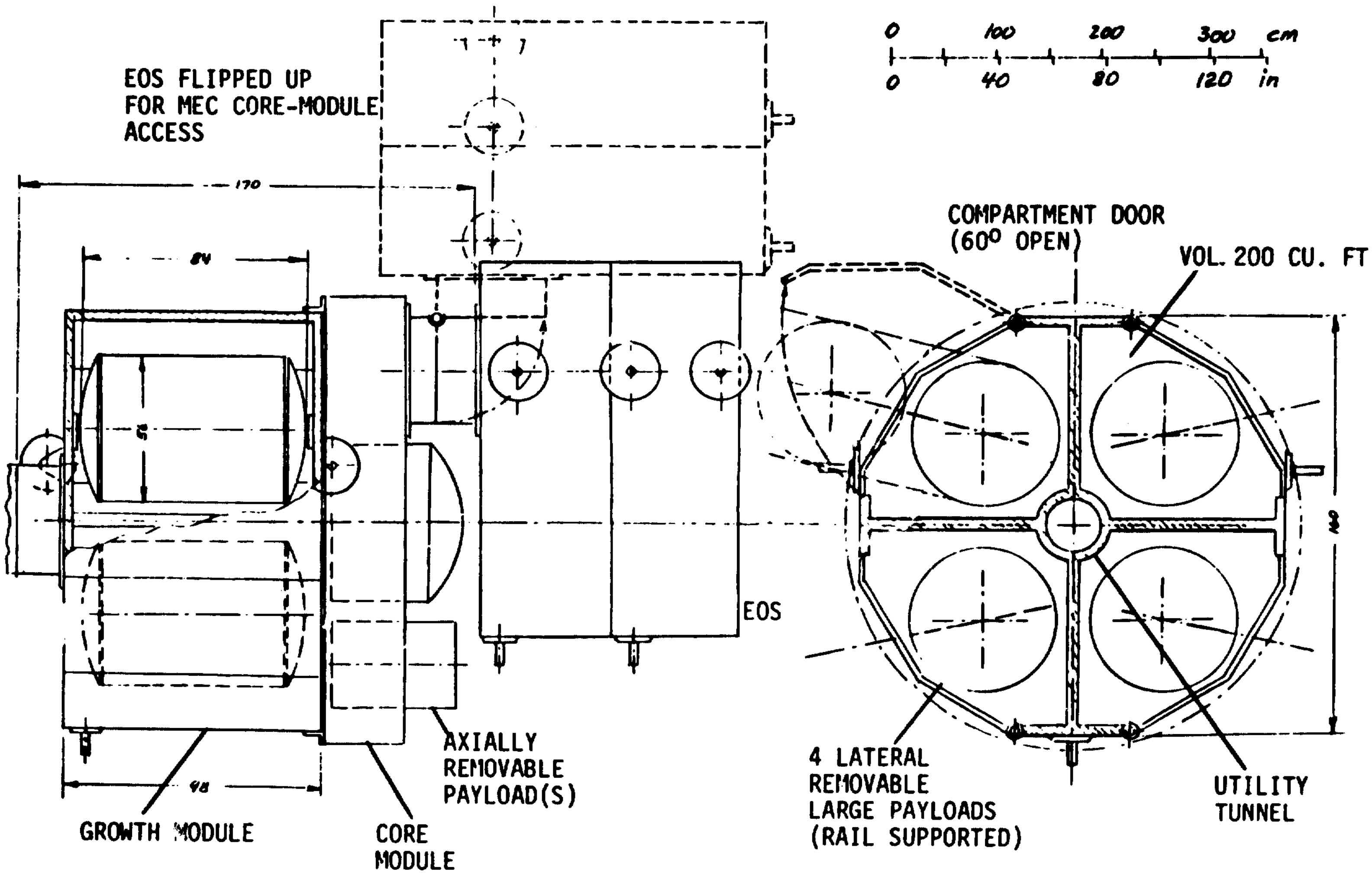


Figure 4-12. All-Up MEC Configuration, Including EOS

servicing access would be absorbed by the MEC design rather than by EOS. A simpler, though operationally less attractive, option would involve EOS removal to a temporary parking location by the Shuttle remote manipulator whenever MEC core module access is required.

Note that the EOS swing-out concept illustrated here is made feasible by the off-center location of the berthing adapter.

Figure 4-13 shows an isometric view of the all-up MEC with a full payload complement. The drum-shaped, twelve-sided growth module is shown with one of the four payload compartment doors opened. Lateral access to the payloads is illustrated, with one payload canister extended on guide rails for servicing or removal. Payload changeout will require handling by the RMS with EVA crew assistance. RMS grapple fixtures required for MEC deployment or stowage and for payload changeout will be inserted manually by the crewman into receptacles provided for this purpose.

4.4.4 Selected MEC Concept Summary

Principal features, dimensions and weight estimates of the selected design concepts for the initial and all-up MEC are summarized in Table 4-7. The spread of estimated weights ranges from 8360 to 10,000 lb for the initial MEC and from 13,920 to 25,260 lb for the all-up MEC, including 20% for weight contingencies. The large weight variation in the latter case is due to the 1000 to 3000 lb weight range for each of the four major payload units carried in the growth module, based on results of the payload survey conducted in MEC Study, Part 1 (Reference 5). The above weights do not include the 10,000 lb estimated for EOS.

4.4.5 Design Implications of MEA-C-to-MEC Evolution

The evolution from MEA-C to the initial MEC and subsequently, to the all-up MEC should be planned with emphasis on system and component commonality where this can be achieved without sacrifice in meeting program objectives and where it results in genuine cost savings.

This consideration translates into a design approach where the all-up MEC definition will have a retroactive impact on design features of the initial MEC. The initial MEC design concept similarly should reflect upon MEA-C and thus influence its design characteristics. Programmatically,

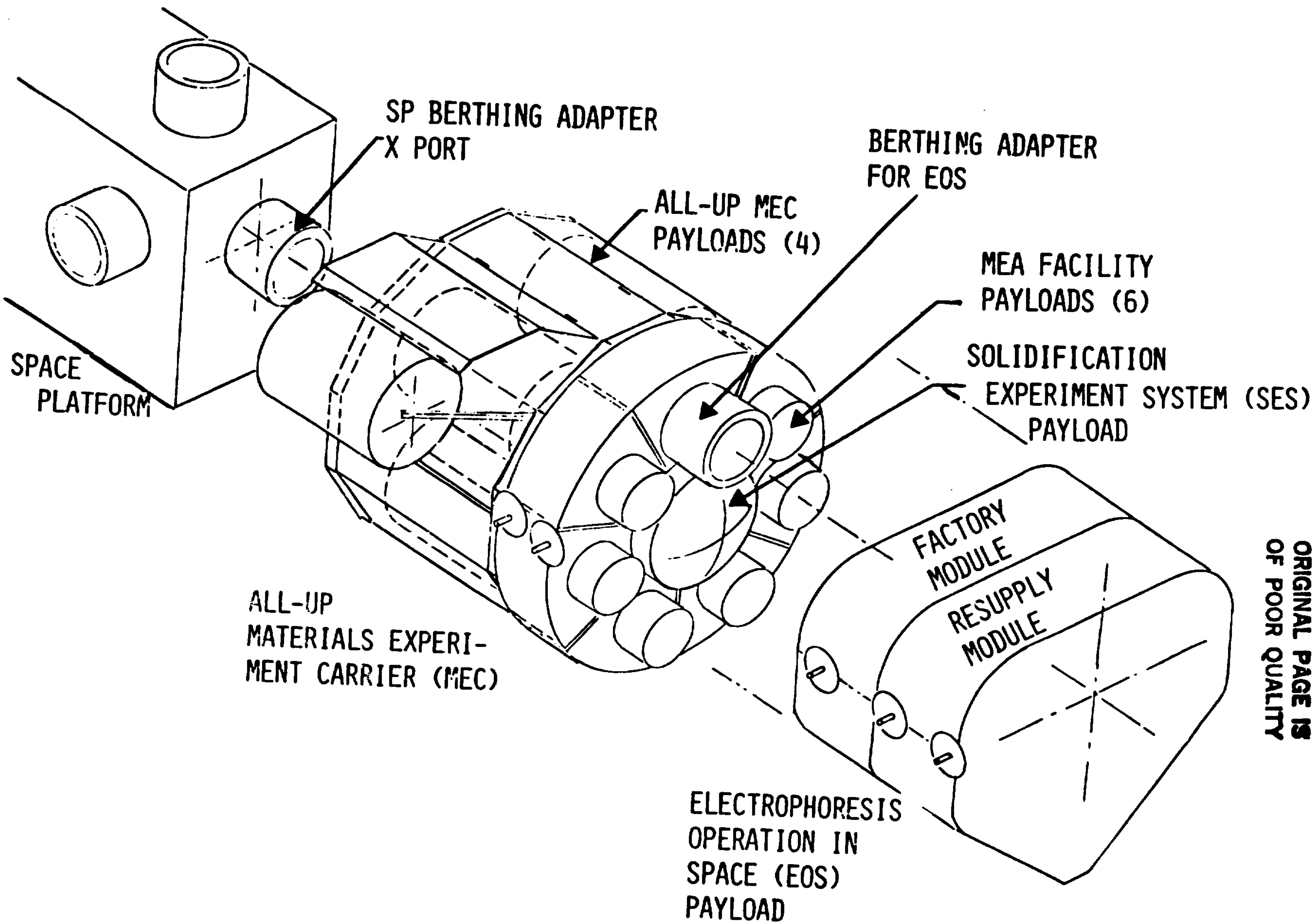


Figure 4-13. All-Up MEC Configuration With Payloads

Table 4-7. Selected MEC Concept Summary

ITEM	INITIAL MEC		ALL-UP MEC	
HOST VEHICLE	INITIAL SPACE PLATFORM (12.5 KW)		GROWTH SPACE PLATFORM (25 KW)	
CONFIGURATION	MEA SPOKED DISC, MODIFIED 14 FT DIAMETER, 30 IN. NET LENGTH (70 IN. GROSS LENGTH, INCL. ADAPTERS)(1)		INITIAL MEC (CORE MODULE) IN TANDEM WITH GROWTH MODULE (MEC B) 14 FT DIAMETER 130 IN. NET LENGTH (170 IN. GROSS LENGTH, INCL. ADAPTERS) (1)	
PAYLOADS	SES, 6 ADVANCED MEA FACILITIES, EOS (ATTACHED IN TANDEM)		SES, 5 TO 6 SMALL PAYLOADS (IN CORE MODULE), 4 LARGE PAYLOADS (GROWTH MODULE), EOS (ATTACHED IN TANDEM)	
SUBSYSTEMS	POWER DISTRIBUTION AND CONTROL, THERMAL CONTROL,(2) CDMS, CONTAMINANT CONTROL/RELEASE, STRUCTURE AND MECHANISMS			
EST. WEIGHT (LB)				
STRUCTURE	1330(3)		2850(3)	
SUBSYSTEMS	800		960	
PAYLOADS(4)	4,480 MIN	6,290 MAX	8,840 MIN	18,300 MAX
CONTINGENCY (20%)	1,390	1,680	2,320	4,200
TOTAL	8,000 MIN	10,100 MAX	14,970 MIN	26,310 MAX

(1) ADD 40 IN. FOR SP AND EOS ADAPTERS (DOES NOT INCLUDE 44-IN. EXTENSION ARM)
(2) ALL-UP MEC MAY INCLUDE AUXILIARY RADIATOR
(3) INCL. 160 LB FOR 2 ADAPTERS
(4) NOT INCLUDING 10,000 LB FOR EOS

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Table 4-8. Design Implications of MEA to All-Up MEC Evolution

MEA-C ⟷ INITIAL MEC

- CENTER COMPARTMENT SIZED TO ACCOMMODATE SES (60 IN DIAM.)
- SUBSYSTEMS HOUSED IN ONE OF TRAPEZOIDAL COMPARTMENTS
- PROVISIONS FOR ADAPTER ATTACHMENT ON BOTH SIDES OF MEA DISC
- AXIAL PAYLOAD ATTACHMENT
- MODULAR SUBSYSTEM DESIGN FOR GROWTH TO MEC (WHERE POSSIBLE)
- COMPATIBILITY OF SUBSYSTEMS WITH EOS SUPPORT

INITIAL ⟷ ALL-UP MEC

- SERVICING REQUIREMENT REFLECTED IN P/L ATTACHMENT PROVISIONS
- MODULAR GROWTH OF SUBSYSTEM CAPACITY
- PROVISIONS FOR AUXILIARY RADIATOR ATTACHMENT
- POWER, SIGNAL AND FLUID LINES DESINGED FOR CONNECTION TO GROWTH MODULE AND TO ACCOMMODATE ALL-UP MEC LOADS

this implies interactive system planning with a stress on early MEC system definition, at a time when the MEA-C design concept would not yet be firmly established.

Table 4-8 summarizes principal design implications on the MEA-C and the initial MEC configurations that have been identified at this conceptual stage, in the context of the projected evolution to an all-up MEC system.

4.5 MEC SUMMARY FUNCTIONAL BLOCK DIAGRAM

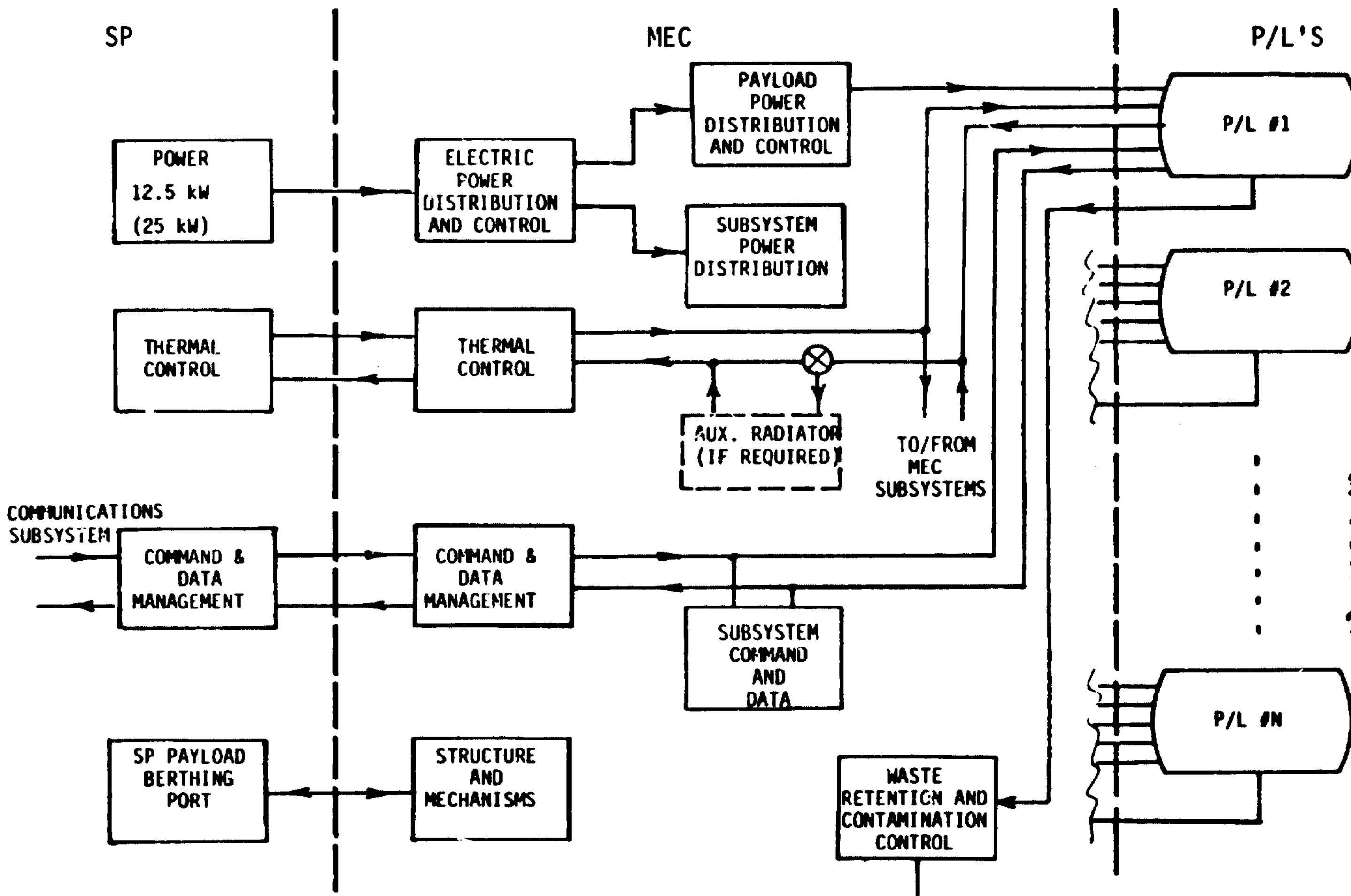
The simplified, summary block diagram shown in Figure 4-14 applies both to the initial and all-up MEC design concepts. It shows, on the left, the relatively few interfaces on the Space Platform side, all of which are combined in the SP payload berthing port, and the services provided across the MEC/payload interfaces, on the right. For simplicity only those power, signal and coolant lines and the contaminant duct to or from one of the n payloads is shown. In the initial MEC these payloads include SES, six MEA facilities and EOS not specifically identified in the chart. In the all-up MEC four additional payloads are accommodated. Interface connections to the various payloads are similar except for EOS which is attached to an external berthing port. It has been baselined that gasses required by payloads will be provided by the payloads. For the all-up MEC this should be the subject of a trade off analysis when a more definitive understanding of the payloads is available.

The block diagram only shows interfaces with the Space Platform, omitting those with the Orbiter. The latter interfaces will be similar to those shown in Figure 4-14 except for involving much lower power supply and thermal control capacities and lower data rate signals to and from the MEC CDMS. Electrical cables and coolant lines will be connected via an Orbiter umbilical. The structural interface between MEC and Orbiter is provided by longeron and keel trunnions on the MEC and by corresponding retention fixtures in the Orbiter bay.

4.6 PAYLOAD ACCOMMODATION

4.6.1 Payload Accommodation Criteria

The selected design conepts for the initial and all-up MEC are driven by payload accommodation criteria which include:



NOTE: DOES NOT INCLUDE MEC/ORBITER INTERFACES

Figure 4-14. MEC Summary Functional Block Diagram

1. Adequate mounting space for each payload type and adequate capacity for the desired number of payloads to be carried.
2. Standardized MEC-to-payload interface characteristics (except those for EOS accommodation).
3. Effective payload support by MEC subsystems, including resource allocation and control.
4. Convenient payload access
   (a) On the ground: for integration, checkout, repair, refurbishment and changeout
   (b) On orbit: for servicing, including payload changeout and/or sample material resupply/removal (on all-up MEC only).
5. Effective protection of payloads and sample material against adverse environments, rough handling, accidental physical damage, internal MEC system malfunctions or power outage.

In addition, the objective of providing for largely autonomous payload operation governs the electrical subsystem architecture and payload interface design. This autonomy implies a reliance on payload-peculiar, individually programmed and controlled micro-event sequences with the MEC central computer responsible only for executive control functions of the payloads. The objectives are MEC design simplification, operational convenience and greater payload accommodation flexibility.

These criteria and requirements have been adhered to in the selected design approach to the extent that payload design characteristics, functional requirements and operational profiles are currently defined.

Sources that were available in this study include the Teledyne Brown Engineering report (Reference 1) covering general characteristics of initial MEC payloads (SES, Advanced MEA payloads and EOS) and the comprehensive MPS Payload Data Handbook compiled by TRW in MEC Study Part 1 (Reference 5). More specific payload design characteristics will be required to permit in-depth definition of payload accommodation and interface design.

4.6.2 Summary of MEC Payload Accommodation Capabilities

The initial MEC configuration provides space for up to six MEA type payloads plus an advanced version of SES. As an option, a berthing port for EOS attachment is provided. The all-up MEC accommodates four additional large payloads.

MEC also provides the capability of accommodating commercial MPS payloads, other than EOS, or quick-look, carry-on payloads. These may be flown in one of the payload compartments. Therefore, payload-to-MEC interface flexibility is provided to widen the utilization of MEC as a MPS host vehicle.

Table 4-9 lists payload accommodation issues that were identified in the study and to which the capabilities of the selected MEC design are tailored. They are covered in Sections 4.4 and 5.

MEC power distribution, thermal control and command/data management subsystems provide functional support in accommodating the various payloads. The payloads themselves will carry corresponding self-contained subsystem elements that permit semi-autonomous operation under centralized, executive MEC control, as necessary.

Payloads carried by the initial MEC will be hard-mounted with no on-orbit access and/or changeout provisions, to save development cost, except for EOS, which can be attached to or removed from MEC as required, according to mission plans. The all-up MEC provides payload access for servicing and changeout as discussed in Section 4.4.

MEC provides flexibility in accommodating payload complements with a wide range in resource requirements, processing/orbit stay times, weights and volumes, Simultaneous and/or time shared, sequential payload operating modes will be used to assure compatibility with available resources and required process times.

Initial MEC missions in 1987/88 will be limited to 180 days duration based on the currently planned minimum time interval between Shuttle revisits to the SP. Therefore, no on-orbit MEC servicing or payload changeout will be performed in these early missions, but the entire MEC will be returned to earth by the Shuttle after 180 days. If two MEC vehicles are part of the inventory, they may be launched in an alternating sequence at 180 day intervals.

4.6.3 Payload Accommodation Issues Requiring Further Study

Areas requiring further study and definition include detailed payload power requirements (peak and average power, energies and load profiles), heat rejection profiles, command and telemetry data profiles, sample

Table 4-9. Payload Accommodation Issues

1. PAYLOAD INSTALLATION PROVISIONS (RAILS, DRAWERS, ROLLERS)

2. RETENTION SYSTEMS (TIE TOGETHER STRUCTURE)

3. ACCESS TO THE PAYLOADS - ON GROUND AND ON-ORBIT (LIDS, DOORS. PLATES, HAND-HOLDS, COLOR CODES, LIGHTING, QUICK/SURE MEANS OF IDENTIFICATION OF COMPONENTS)

4. MEC-TO-MEC PAYLOADS STANDARD INTERFACES (POWER, DATA, THERMAL, STRUCTURE)

5. DEPLOY/RETRIEVAL DEVICES (HOLDS, HANDLING FIXTURES, GRAPPLES)

6. CONTAMINATION CONTROL (SENSORS, VENTING SYSTEMS)

7. MEC SUBSYSTEM SERVICES

CDMS	ELECTRIC POWER	HEAT REJECTION
• DATA PACKETIZING • COMMAND/CONTROL • STATUS INSTRUMENTATION (G-LEVEL, TIME) • SOFTWARE • SELF CHECKING	• DISTRIBUTION • REGULATION/CONTROL • INDEPENDENT STAY ALIVE	• COOLAND LOOP AND PUMPING HARDWARE • COLD PLATES • SENSORS

8. WHERE MPS PAYLOADS CONSTRAIN MEC TO POINT DESIGNS, CONSIDER RECONFIGURATION OF THESE PAYLOADS

storage capacity, processing rates and replenishment cycles. We recommend that this effort be deferred until specific candidate payloads, their design characteristics, support requirements and operational modes have further evolved.

4.6.4 Resources Available for Payload Accommodation

A realistic account of MEC payload accommodation will require more detailed and updated information on the resources available on typical Space Platform missions (for initial and growth versions of the SP). This will critically depend on resource requirements and priorities of other users that may share these missions. By current estimates, only 7 to 9 kW of average power might be allocated to MEC on typical mission profiles of the initial 12.5 kW Space Platform, whereas the initial MEC payload complement has a projected average power requirement of about 10 kW, even with MEA payloads operating in a fully time shared mode. This is illustrated in Figure 4-15. The bar graph, on the left, shows minimum and maximum power requirements by EOS, SES and individual MEA facilities, according to the Teledyne-Brown report. As the chart shows, the maximum required power for the combined EOS, SES and one MEA payload operation would exceed the available power supplied by the SP by more than 1 kW even if MEC were the only user. The specific MEC power utilization profile must therefore be established as part of MEC mission planning.

Note that the extra power available seasonally in short-eclipse or eclipse-free Space Platform orbits (at high orbit inclination) does not greatly alter the power sharing profile, because of the infrequent occurrence and relatively short duration of these power peaks (typically 70 to 100 day intervals between peaks and durations of 5 to 15 days).

4.7 MEC SYSTEM INTERFACES

The selected initial and all-up MEC design concepts meet interface requirements previously discussed in Section 3.4. This section covers system interface issues between MEC and the Space Platform, the Shuttle Orbiter and MEC payloads, including EOS, that are not discussed elsewhere in this report. Some system design interface issues were previously discussed in Sections 4.3 and 4.4, subsystem design interfaces are covered in Section 5, operational interfaces in Section 6. Payload interfaces are

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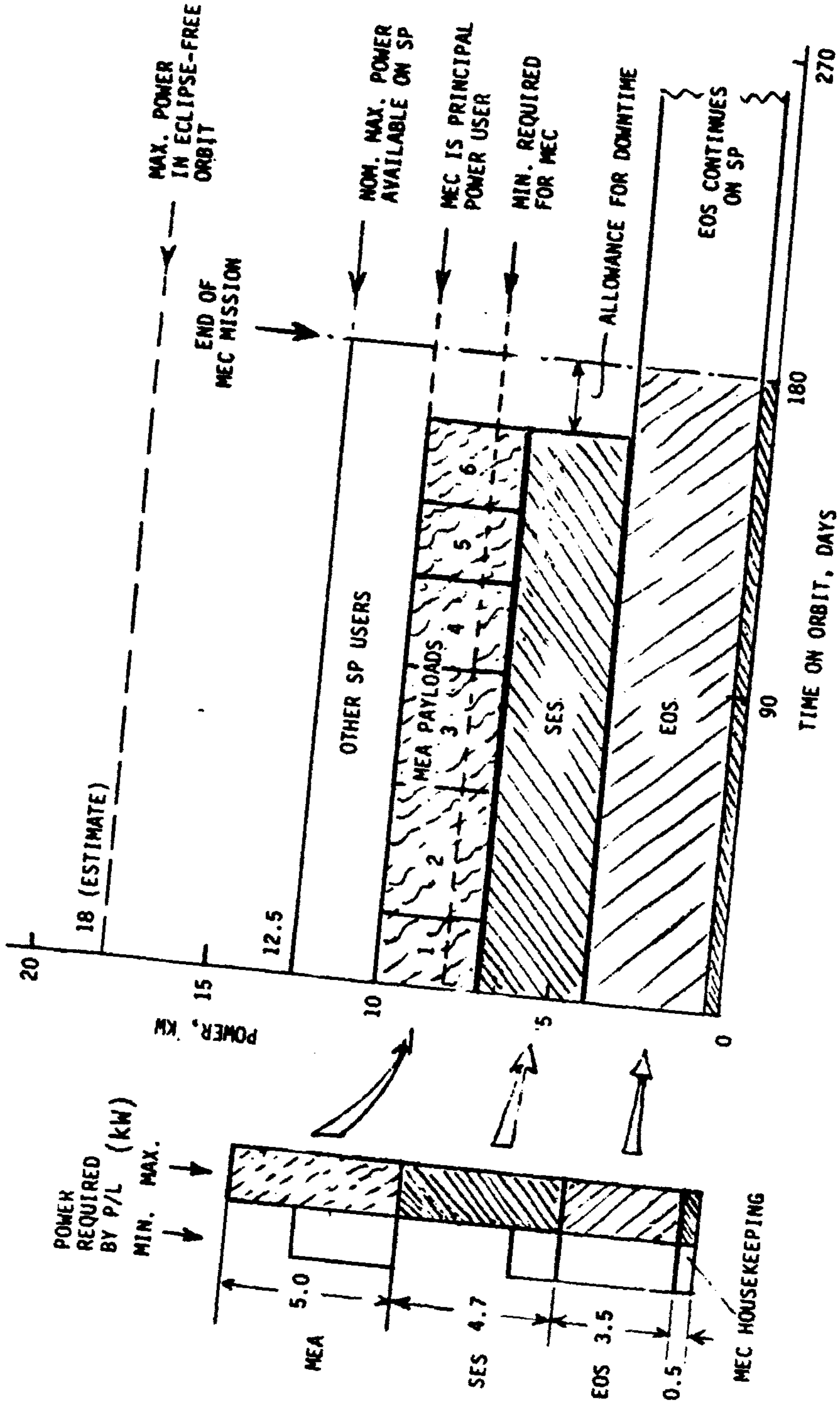

Figure 4-15. Power Sharing by Initial MEC Payloads

discussed in Sections 4.4 through 4.6 and in Section 5. Reference should be made to those sections for issues not covered here.

4.7.1 MEC/Space Platform Attachment

Table 4-10 lists interface concerns involving MEC-to-Space Platform attachment. Results of the study indicate a satisfactory solution of most of these issues except where SP design and operating characteristics have not been fully defined, such as accessibility by the Orbiter RMS arm of MEC or MEC payload equipment on the SP starboard side. This may be alleviated if the SP can be reoriented appropriately on its Orbiter berthing platform. It is likely that SP design requirements (not stated in the baseline reference design, Reference 3) will be revised to require such a reorientation capability. (See also the discussion of RMS access to MEC or MEC payloads, in Section 4.7.2).

One major MEC/SP attachment constraint involves clearance of stay-out envelopes defined for SP appendages (solar array, radiator, trunnion support structures and SP/Orbiter berthing arm) and other SP payloads.

Figure 4-16 shows two possible MEC berthing positions on the Space Platform. When attached to the aft berthing port (x-port), MEC requires a 3.5 ft extension arm for clearance of the SP berthing arm envelope (bottom) and the payload demarcation line (top). This demarcation envelope is not firmly determined at present, but preliminary information received from MSFC defines it as the bisector between center lines of the x- and z-ports, x- and y-ports, and z- and y-ports, respectively.

In the upper (z-port) berthing position, indicated in dashed outline, the MEC disc must clear the SP radiator panel and the envelope of the SP sill trunnion and support structure next to the z-port. Use of an extension arm may not be required in this instance.

Note that use of the extension arm is not a requirement unique to MEC. It will also be required for attaching the EOS or other payload carriers directly to the SP. The clearance envelopes and other attachment constraints are still to be more firmly defined by MSFC. It is assumed in this study that the extension arm will probably not have to be taken into orbit on each MEC launch and that MEC launch costs will not include length-dependent charges for transportation of this arm.

Table 4-10. MEC-To-Space Platform Attachment Issues

1. Payload Port Selection	• MEC will fit on any available payload port and avoid interference with SP users • Z-port often assigned to MEC because other users prefer more favorable viewing from +X or + Y ports
2. MEC Size and Mass Property Issues	• Minor shading of solar array may occur if MEC on $\pm$ Y ports. (Typically, less than 8% shading during 25% of daylight cycle, resulting in about 2% power loss) • Long MEC structure on Z-port or X-port can result in significant micro-g disturbances (a) due to gravity gradients in certain SP orientations, (b) due to SP rotation rates and accelerations • Asymmetrical mass properties resulting from MEC attachment on +Z or +Y ports must be within reboost module thrust vectoring constraints
3. Clearance Envelopes	• MEC requires extension arm to clear stay-out envelopes of SP berthing arm and adjacent payloads if berthed at X-port
4. RMS Accessibility	• RMS reach of MEC, or MEC payload equipment, on SP starboard side may require detailed analysis depending on SP/Orbiter berthing provisions
5. EOS Accommodation	• Advantages of EOS accommodation by MEC: avoids occupancy of an extra SP port, simplifies SP interface

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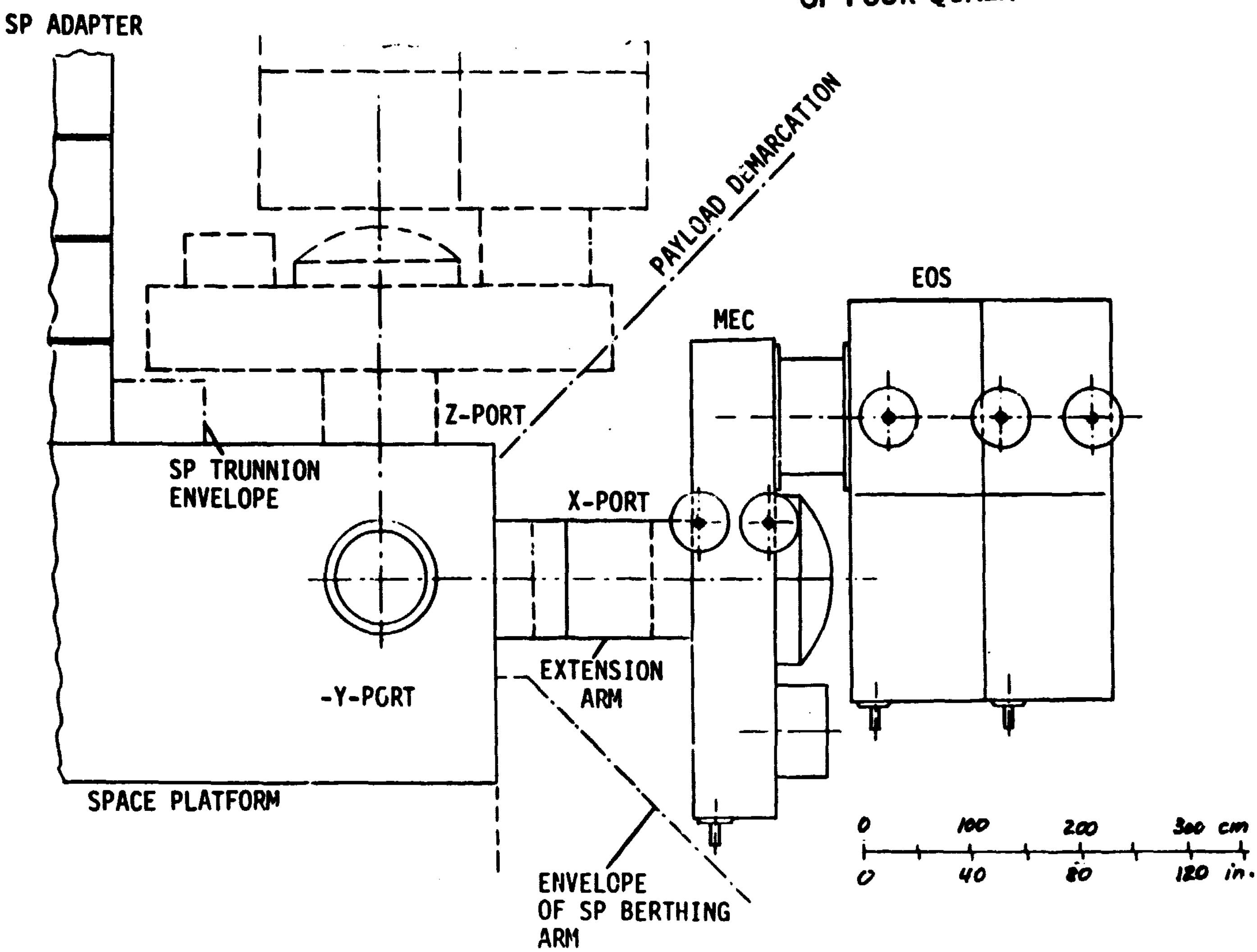

Figure 4-16. Alternate Berthing Positions of Initial MEC

4.⁻.2 MEC/Orbiter Interface Issues

Table 4-11 lists interface issues between MEC and the Orbiter. Items of principal concern include structural (load transfer) interfaces, handling, and electrical interfaces with the Orbiter. Crew operation interfaces will be discussed separately in Section 6.

None of the items identified here involve areas of particular operational difficulties or implementation problems, but all need careful attention in interface design and mission planning.

The preferred RMS grapple fixture placement, as stated in the table, is on the top of the MEC hull, for convenient RMS access during MEC unstowing/restowing from/to the cargo bay and SP attachment/detachment. Use of a removable grapple fixture (recommended by astronauts in recent discussions

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Table 4-11. MEC/Orbiter Interface Issues

STRUCTURAL/LOAD TRANSFER	
● SILL AND KEEL TRUNNIONS	- INITIAL MEC: 3 POINT ATTACHMENT PREFERRED OVER 4 POINT ATTACHMENT. REQUIRES ACTIVE KEEL FITTING, VISUAL MONITORING OF ON-ORBIT RESTOWAGE - ALL-UP MEC: 5 POINT ATTACHMENT, ABOVE CONSTRAINTS DO NOT APPLY
● PLACEMENT IN ORBITER	- INITIAL MEC FRONT OR AFT END OF CARGO BAY - ALL-UP MEC MID OR AFT SECTION TO MEET C.M. CONSTRAINTS, DEPENDING ON COMPANION PAYLOAD MASS
HANDLING	
● RMS ACCESSIBILITY/REACH	- GRAPPLE FIXTURE PREFERABLY TOP MOUNTED. REMOVABLE, PLUGGED IN BY EVA CREWMAN - GRAPPLE FIXTURES ON EXCHANGEABLE HEAVY/BULKY PAYLOAD UNITS - RMS REACH STUDIES NECESSARY
● UMBILICAL	- TO BE DISCONNECTED/RECONNECTED BY EVA CREWMAN
ELECTRICAL	
● POWER	- STAY ALIVE POWER (FOR HEATERS, COMMAND AND TELEMETRY) } VIA UMBILICAL
● COMMANDS/STATUS SIGNALS	- SIGNAL INTERFACE TO FLIGHT DECK } VIA UMBILICAL

at NASA/JSC) would avoid the problem of grapple fixture protrusion into the cargo bay dynamic envelope but necessitates an added EVA crew task in MEC deployment/retrieval.

As an alternative, a fixed grapple installation on a recessed mounting plate could be used to avoid unacceptable stem protrusion without causing a significant decrease of MEC payload volume. EVA crew involvement in grapple insertion and removal would thus become unnecessary.

Note however that the use of removable grapples inserted in appropraite receptacles on payload canisters is practically a necessity in all-up MEC payload servicing. Otherwise, an excessive proportion of payload storage volume inside the closed MEC growth module compartments would be sacrificed by fixed grapple installation.

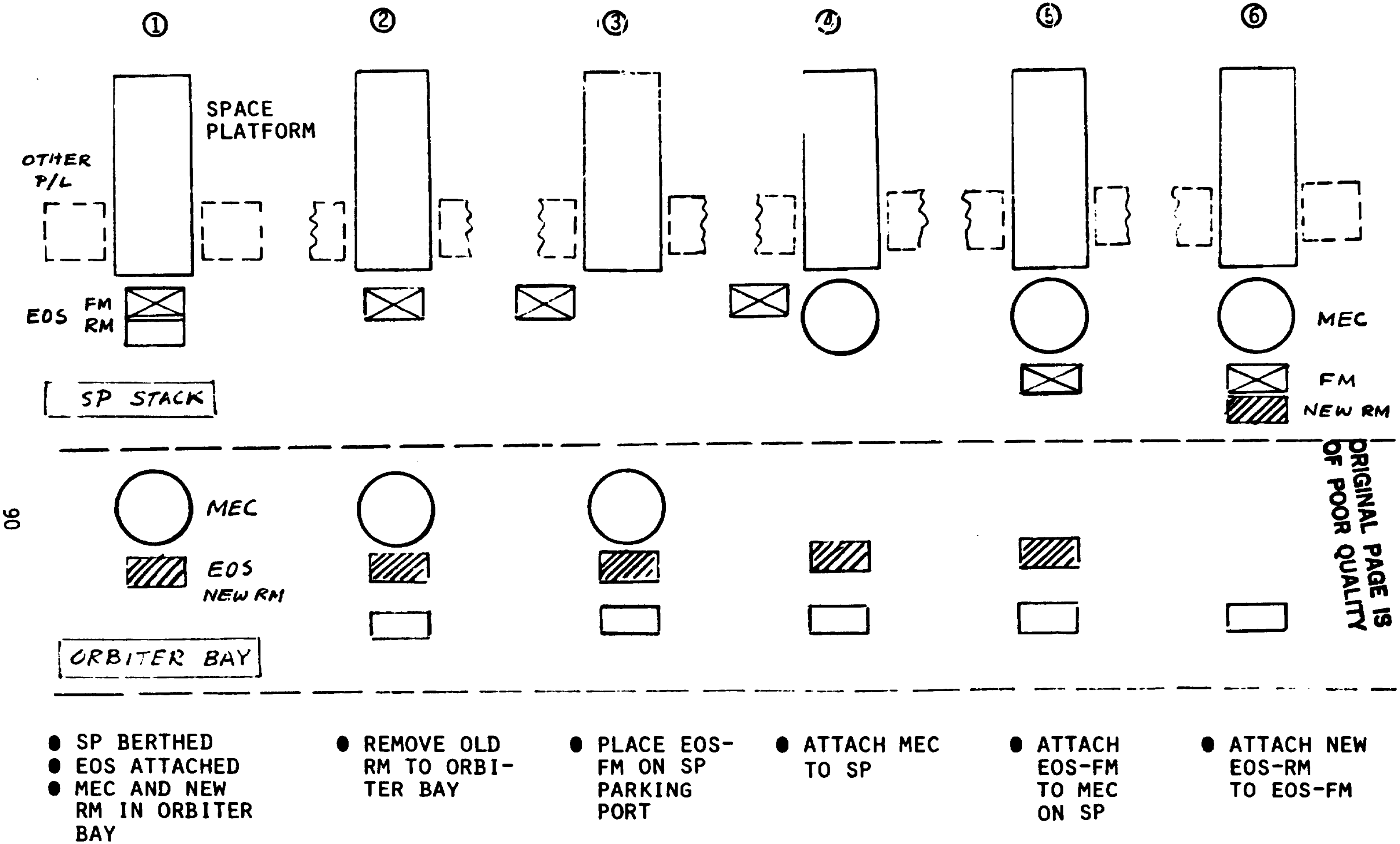
4.7.3 MEC/EOS Attachment and Detachment by RMS

As previously discussed, the EOS will operate either directly attached to the Space Platform or as a MEC-attached payload. A typical RMS handling sequence of MEC and EOS designed to accommodate the two EOS operating modes is illustrated schematically in Figure 4-17. It involves six steps of RMS activity including MEC unstowing and attachment to the SP, EOS factory and replacement module detachment, stowing/unstowing and reattachment. It also requires the use of a temporary parking port on the SP to hold the EOS factory module (FM) while rearranging the other units in sequence. Availability of an SP parking port makes temporary EOS-FM stowage in the Orbiter bay unnecessary. This handling sequence, while time-consuming and complex, appears necessary to implement the single-port attachment concept devised for greater Space Platform utilization flexibility.

4.8 ASSESSMENT OF SELECTED MEC CONFIGURATION

Table 4-12 is a rating chart that gives an assessment of the selected initial and all-up MEC design concepts with regard to meeting key functional and operational requirements. Four of these pertain to payload accommodation issues.

Three rating levels, 1-satisfactory, 2-good and 3-excellent, are used in this assessment. Most of the MEC design characteristics listed in the table received high ratings. Those with lower ratings are generally of



NOTE: 1. EACH STEP INVOLVES A SEPARATE RMS TASK
2. ASSIGNMENT OF SAME BERTHING PORT TO EOS AND MEC IS ASSUMED

LEGEND: FM-FACTORY MODULE; RM-RESUPPLY MODULE OR

Figure 4-17. Typical MEC/EOS Handling Sequence During SP Revisits

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Table 4-12. Assessment of Selected MEC Configuration

CHARACTERISTICS	RATING: INITIAL MEC 1	INITIAL MEC 2	INITIAL MEC 3	ALL-UP MEC 1	ALL-UP MEC 2	ALL-UP MEC 3	REMARKS
1. COMMONALITY WITH ADVANCED MEA (MEA-C)			●			●	ADAPTED MEA DESIGN
2. COMPACTNESS			●			●	
3. NUMBER OF PAYLOADS ACCOMMODATED			●			●	UP TO 7 INITIAL MEC UP TO 10 ALL-UP MEC
4. FLEXIBILITY OF PAYLOAD ACCOMMODATION			●			●	
5. P/L SIZE ACCOMMODATED		(1) ●				●	(1) LENGTH ≤ 50 IN
6. P/L ACCESS FOR SERVICE/CHANGEOUT							
- ON GROUND			●			●	
- ON ORBITER			●		(2) ●		(2) GROWTH MODULE P/L'S INACCESSIBLE IN CARGO BAY
- ON SPACE PLATFORM (SORTIE MODE)	N/A	N/A	N/A			●	
7. EASE OF GROWTH FROM INITIAL TO ALL-UP MEC			●			●	
8. ORBITER STRUCTURAL INTERFACE	(3) ●					●	(3) CONSTRAINTS ON LOAD TRANSFER VIA TRUNNIONS
9. RMS HANDLING ACCESSIBILITY/CONVENIENCE		●			●		GRAPPLE LOCATION
10. COMPATIBILITY WITH SP PLACEMENT CONSTRAINTS	●			●			EXTENSION ARM REQUIRED
11. AUXILIARY RADIATOR PLACEMENT (IF NEEDED)	N/A	N/A	N/A	(4) ●			(4) CONSTRAINED BY EOS

RATING LEVELS 1-SATISFACTORY 2-GOOD 3-EXCELLENT

lesser importance. Some require further study, e.g., item 8 which involves constraints on load transfer and worst case natural bending frequencies for the initial MEC configuration. Explanations of entries are given in the last column.

5.0 SUBSYSTEMS

This section presents the selected subsystem concepts for the initial MEC design. However, since easy, economical growth to all-up MEC capabilities is a major design objective, each of the subsystem sections also will include a discussion of the initial to all-up capability transition. This growth will be accomplished through design modularity or modification rather than replacement of principal subsystem elements.

In most other respects the MEC subsystem design approach corresponds to the approach previously adopted in the MEC Study, Part 1 which is, in part, reflected here.

5.1 FUNCTIONAL DESIGN APPROACH

As discussed in Sections 3 and 4 the preferred MEC functional design approach is oriented toward decentralization of support functions. Individual payloads will be designed to provide their own, dedicated power processing, data processing, operational control and sequencing and other related support. MEC subsystem functions primarily involve control and support of the operation of the MEC system and payloads as a whole. The objective is to permit 1) greater convenience of payload changeout, both on the ground and on orbit, 2) flexibility of payload composition and, 3) autonomy of payload operation. Item 1 implies simplification of the MEC-to-payload interface and standardization of the interface design.

A design with more centralized support functions probably would allow some savings in equipment development cost and in payload volume and weight but would not meet the objective of maximum payload autonomy and changeout convenienve.

The system functional block diagram, Figure 4-14 (Section 4) reflects the above design approach. MEC subsystems will provide the same functional support services to all payloads. Each payload unit is subdivided into a support and a process module, with the support module performing those subsystem functions delegated to payloads by the decentralized design approach as well as functions that are payload-peculiar.

Payload functions and operations within MEC are structured in a hierarchy analogous to MEC as a Space Platform payload. The SP allocates its resources to the various payloads in accordance with a preassigned or updated/commanded master schedule. It performs executive control over MEC operations but does not get involved in the details of MEC operating procedures, command and data flow, time schedules and processing sequences. MEC operates largely in an autonomous mode subject to resource monitoring and control by the SP.

Analogously, MEC allocates and distributes resources available from the SP to the various MEC payloads according to a predetermined protocol. It exercises executive control over payload operations but will not be involved in, or support details of payload processing functions and sequences. The payloads thus operate largely in an autonomous mode.

Contingencies anywhere in this hierarchy are first responded to at the local level, to achieve immediate protection and/or correction. A response at the next higher level will be prompted by warning signals and other indications of persistent, uncorrected malfunctions/anomalies at the lower level. Thus MEC's centralized system and payload control functions will respond to anomolies occurring in any payload. Automatic system checkout and diagnostic functions also are included as part of centralized control.

The MEC subsystem requirements and implementation summary listed in Table 5-1 reflects the decentralized design concept.

The Space Platform provides a major part of spacecraft functional support while MEC subsystems provide necessary interface services between the Space Platform and the various MEC payloads.

The structure subsystem houses payloads, payload support equipment and other MEC subsystems. It provides adapters for attachment to and accommodates interfaces with the SP, the Shuttle and Ground Support Facilities. The subsystem is designed to provide modularity and flexibility to minimize total MEC weight and length, as required for transportation cost economy.

The power subsystem distributes conditioned power to MEC payloads and other subsystems, interfacing either with the SP or the Orbiter.

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Table 5-1. MEC Subsystems Summary

Subsystem	Requirements	Comments
Structures	• Accommodate payloads, MEC subsystems and payload-required support equipment. Provide ease of access. • Provide adapters for attachment to the Shuttle, Space Platform and RMS.	• Develop on-orbit accessible modular design which provides maximum payload flexibility/interchangeability. • Conform with Shuttle trunnion and keel tiedowns.
Thermal Control	• Interface with (as required) the SP heat rejection system. • Provide temperature control and heat rejection for MEC subsystems, payloads and payload required support equipment.	• Accommodate high and low-temperature payloads and low temperature subsystems and support equipment.
Power Distribution	• Provide interfaces between payloads and SP or Shuttle. • Protect and isolate payloads and SP/Shuttle from each other.	• Receive, condition, distribute, and control power to payloads and MEC subsystems. • Provide EMI and RFI shielding.
Command/Data Management	• Provide interfaces between payloads and SP or Shuttle. • Provide MEC/payload supplemental data storage as required. • Provide command and control of MEC subsystems and payloads in conjunction with SP. • Integration, pre-launch, deployment and on-orbit payload condition checkout.	• Optimize data handling/management between MEC/payload and SP or Shuttle. • Central command and control on MEC, subcommands in payload support module as required. • Provide checkout and diagnostic capability.

The command/data management subsystem supports the data flow to and from MEC payloads and provides interfaces with the Space Platform and the Orbiter. The SP communication subsystem establishes the interface with mission support facilities on the ground (Mission and Payload Operation Control, see below). This subsystem also provides for payload, subsystem and support equipment checkout during prelaunch integration and in all subsequent mission phases. Diagnostic routines are provided for fault detection and correction as required.

The thermal control subsystem provides the required temperature control and heat rejection for the payloads, and MEC subsystems. It provides for use of the heat rejection capability available through the Space Platform payload heat exchanger at compatible temperature levels and coolant flow rates.

Structure and mechanisms have been previously discussed in conjunction with configuration design with additional discussion to be presented in Section 5.6. Power distribution, command/data management and thermal control subsystem design approaches will be discussed in Sections 5.2 through 5.5 below. Section 5.8 presents a proposed approach to breadboard development of key subsystem elements.

5.2 MEC ELECTRICAL DESIGN

The MEC electrical design includes power distribution and control, command and data management and the interfaces between these subsystems and corresponding Space Platform subsystems, on one hand, and MEC payload units, on the other. Functional allocations in the electrical design concept were previously shown in detail in Reference 6 and are summarized in Table 5-2.

Figure 5-1 illustrates the flow of power generation, distribution and control activity between system elements, as indicated by solid, dashed and dotted lines, respectively. This chart illustrates the "hand shaking" that must occur between the various units in effective data gathering, decision making and command generation and in control of system operation, mode switching or system reconfiguration. Decision making is based (1) on the data gathered, as indicated by the data flow lines, and (2) on stored instructions based on mission protocol.

Figure 5-2 shows a top level protocol table which indicates originators and recipients of commands and telemetry data and also lists which system elements will perform command authorization/approval and data analysis, as part of the protocol. Related decision functions performed at the various levels in the command hierarchy are summarized in Figure 5-3.

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Table 5-2. Electrical System Functional Allocations

GROUND CONTROL (POCC/SPCC)	SPACE PLATFORM	MEC	MEC PAYLOAD
GOALS • Mission planning • Optimum use of MEC, SP and STS • Monitoring/control of flight operations	• Meet user load requirements • Executive control of users • Maintain ground links via TDRSS	• Support P/L load require- • Maximize productivity of mission • Monitor/control autonomous operations	• Operate cost-effectively and productively • Share resources optimally
POWER DISTRIBUTION & CONTROL • Monitor adherence to resource allocation, mission protocol	• Supply power to users per predetermined allocation • Monitor/control power utilization by P/L's	• Distribute power to MEC payloads per established program • Monitor loads on distribution system • Shed loads if necessary	• Utilize power effectively • Protect against overloads • Provide additional power conditioning
COMMAND/DATA FLOW & MANAGEMENT • Accommodate PI participation in MEC/payload monitoring, control, data analysis • Transmit commands, receive housekeeping & payload data • Exercise MEC control in critical events	• Distribute commands, acquire data from MEC • Executive control of MEC operating modes • Provide data storage for delayed dump	• Control MEC operations • Interface with SP data bus • Distribute incoming commands • Acquire P/L data & transmit to SP for communication to POCC • Executive control of P/L's • Checkout, diagnostic routines	• Control P/L processing sequences • Accept commands • Acquire experiment data, transmit to MEC CDMS • Perform checkout, diagnostic routines
MEC/MEC PAYLOAD INTERFACE CONTROL • Monitor/control interface functions • Accommodate PI participation in MEC/PL interface control • Support critical event control	• Transmit commands to MEC, MEC/PL data to ground in support of MEC/PL remote interface control	• Autonomous P/L operation monitoring & executive control • Transfer commands to P/L, P/L data to SP • P/L time-sharing control	• Autonomous operation under MEC executive control • Protect system against P/L malfunctions, overloads

SPACE PLATFORM	MEC
GENERATES PRIMARY POWER	
TRANSFERS PRIMARY POWER AT SP/MEC INTERFACE PROVIDES POWER VIA ONE OR MORE OF THE FOLLOWING SEPARATE - ISOLATED - ACTIVATED BUSES: o 2 120 VDC BUSES o 3 30 VDC BUSES	RECEIVES PRIMARY POWER AT MEC/SP INTERFACE RECEIVES POWER VIA ONE OR MORE OF THE FOLLOWING SEPARATE - ISOLATED - ACTIVATED BUSES: o 2 120 VDC BUSES o 3 30 VDC BUSES
PROVIDES PRIMARY POWER REGULATION ± 1%	DOES NOT PROVIDE FURTHER REGULATION
ACTIVATES SELECTED BUSES VIA: o SP LOGIC o SP SWITCHES	MONITORS BUS AVAILABILITY/BUS LOADING VIA: o MEC TRANSDUCERS o MEC LOGIC
PROVIDES OVERLOAD PROTECTION OF BUSES VIA: o SP BUS MONITORS o SP LOGIC AND PS SWITCHES	PROVIDES NO OVERLOAD PROTECTION WITHIN MEC MONITORS LOADS ON ACTIVATED BUSES
GENERATE MAXIMUM BUS LOADING CRITERIA VIA o SP LOGIC	
NOTIFIES USER(S) OF LOAD CRITERIA VIA o SP LOGIC o DATA BUS	RECEIVES LOAD CRITERIA IMPOSED BY SP VIA o MEC LOGIC o DATA BUS
INITIAL CONTINGENT AND PLANNED MISSION PHASES AND TERMINATION BUS SELECTION AND BUS LOAD CRITERIA GENERATED VIA: o SP LOGIC	COMPARES PAYLOAD LOADS WITH IMPOSED SP REQUIREMENTS IF PS REQUIREMENTS EXCEEDED - DECIDES COURSE OF ACTION COMMANDS PAYLOAD SWITCHES
RECEIVES RELATIVE USER STATUS: o FROM USER LOGIC o VIA DATA BUS o TO SP LOGIC	NOTIFIES SP OF REAL TIME USER STATUS o FROM MEC LOGIC o VIA DATA BUS o TO SP LOGIC
ACKNOWLEDGES USER STATUS: o FROM SP LOGIC o VIA DATA BUS o TO USER LOGIC	RECEIVES STATUS ACKNOWLEDGEMENT o FROM MEC LOGIC o VIA DATA BUS o TO MEC LOGIC
RECEIVES PLANNED USER REQUIREMENTS o FROM USER LOGIC o VIA DATA BUS o TO SP LOGIC	NOTIFIES SP OF PLANNED USER REQUIREMENTS o TO SP LOGIC o VIA DATA BUS o FROM MEC LOGIC
DECIDES AND SCHEDULES BUS CONFIGURATION AND BUS LOADING CRITERIA REQUIRED TO MEET USER REQUIREMENTS BASED UPON USER STATUS AND PLANS WITHIN SP STATUS AND ANTICIPATED CONSTRAINTS VIA: o SP LOGIC	COMPARES EACH PAYLOAD PLANNED REQUIREMENTS WITH PLANNED BUS/LOAD AVAILABILITY
NOTIFIES USER OF SCHEDULED BUS AND LOAD AVAILABILITY FROM SP o FROM SP LOGIC o VIA DATA BUS o TO USER LOGIC	DECIDES COURSE OF ACTION AND IMPACT UPON EACH PAYLOAD
	NOTIFIES EACH PAYLOAD OF BUS/LOAD AVAILABILITY AND TIME LINES: o FROM MEC LOGIC o VIA DATA BUS o TO PAYLOAD(S) LOGIC
	RECEIVES UPDATED PAYLOAD PLANS o FROM PAYLOAD LOGIC o VIA DATA BUS o TO MEC LOGIC

KEY: —— POWER
- - - - COMMANDS
— — DATA

FOLDOUT FRAME

Figure 5-1. Power Distribution and Control Activi

MEC	PAYLOAD(s)
RECEIVES PRIMARY POWER AT MEC/SP INTERFACE	RECEIVES PRIMARY POWER AT PAYLOAD/MEC INTERFACE
RECEIVES POWER VIA ONE OR MORE OF THE FOLLOWING SEPARATE - ISOLATED - ACTIVATED BUSES: o 2 120 VDC BUSES o 3 30 VDC BUSES	RECEIVES POWER (WHEN ENABLED BY MEC CMDS) VIA ONE OR MORE OF THE FOLLOWING BUSES: o 2 120 VDC BUSES o 3 30 VDC BUSES
DOES NOT PROVIDE FURTHER REGULATION	PROVIDES UNIQUE PAYLOAD REGULATION & CONDITIONING
MONITORS BUS AVAILABILITY/BUS LOADING VIA: o MEC TRANSDUCERS o MEC LOGIC	MONITORS BUS AVAILABILITY ENABLED BY MEC AND FLEXIBLY UTILIZES THE AVAILABLE POWER SOURCES
PROVIDES NO OVERLOAD PROTECTION WITHIN MEC	PROVIDES OVERLOAD PROTECTION OF BUSES
MONITORS LOADS ON ACTIVATED BUSES	MONITORS PAYLOAD LOADS VIA: o PAYLOAD SENSORS
RECEIVES LOAD CRITERIA IMPOSED BY SP VIA o MEC LOGIC o DATA BUS	
COMPARES PAYLOAD LOADS WITH IMPOSED SP REQUIREMENTS	
IF PS REQUIREMENTS EXCEEDED - DECIDES COURSE OF ACTION	
COMMANDS PAYLOAD SWITCHES	
NOTIFIES SP OF REAL TIME USER STATUS o FROM MEC LOGIC o VIA DATA BUS o TO SP LOGIC	GENERATES PAYLOAD STATUS DATA o FROM PAYLOAD LOGIC o VIA DATA BUS o TO MEC LOGIC
RECEIVES STATUS ACKNOWLEDGEMENT o FROM MEC LOGIC o VIA DATA BUS o TO MEC LOGIC	CONTINUES PROCESS FUNCTIONS
NOTIFIES SP OF PLANNED USER REQUIREMENTS o TO SP LOGIC o VIA DATA BUS o FROM MEC LOGIC	GENERATES PAYLOAD POWER PLAN (PROFILE) o FROM PAYLOAD LOGIC o VIA DATA BUS o TO MEC LOGIC
COMPARES EACH PAYLOAD PLANNED REQUIREMENTS WITH PLANNED BUS/LOAD AVAILABILITY	NO FURTHER ACTION
	CONTINUES PROCESS FUNCTIONS
DECIDES COURSE OF ACTION AND IMPACT UPON EACH PAYLOAD	
NOTIFIES EACH PAYLOAD OF BUS/LOAD AVAILABILITY AND TIME LINES: o FROM MEC LOGIC o VIA DATA BUS o TO PAYLOAD(S) LOGIC	ACCEPTS NEW DATA o FROM MEC LOGIC o VIA DATA BUS o TO PAYLOAD LOGIC
	CONFORMS TO CONSTRAINTS
RECEIVES UPDATED PAYLOAD PLANS o FROM PAYLOAD LOGIC o VIA DATA BUS o TO MEC LOGIC	GENERATES NEXT PLAN o FROM PAYLOAD LOGIC o VIA DATA BUS o TO MEC LOGIC

Figure 5-1. Power Distribution and Control Activity Flow

GENERATED BY →	SP POCC	MEC POCC	P/L 1 PI	P/L N PI	APPROVED BY →	SP POCC	MEC POCC	P/L 1 PI	P/L N PI
COMMANDS TO SP SYSTEMS	✓					✓			
DATA TO SP SYSTEMS	✓					✓			
COMMANDS TO MEC SYSTEMS		✓				✓	✓		
DATA TO MEC SYSTEMS		✓				✓	✓		
COMMANDS TO P/L 1 SYSTEMS			✓			✓	✓	✓	
DATA TO P/L 1 SYSTEMS			✓			✓	✓	✓	
COMMANDS TO P/L n SYSTEMS				✓		✓	✓		✓
DATA TO P/L N SYSTEMS				✓		✓	✓		✓
GENERATED BY →	**SP**	**MEC**	**P/L 1**	**P/L N**	**ANALYZED BY →**	**SP POCC**	**MEC POCC**	**P/L 1 PI**	**P/L N PI**
TELEMETRY FROM SP SYSTEMS	✓					✓			
DATA FROM PS SYSTEMS	✓					✓			
TELEMETRY FROM MEC SYSTEMS		✓				✓	✓		
DATA FROM MEC SYSTEMS		✓				✓	✓		
TELEMETRY FROM P/L 1 SYSTEMS			✓			P	P	✓	
DATA FROM P/L 1 SYSTEMS			✓			P	P	✓	
TELEMETRY FROM P/L N SYSTEMS				✓		P	P		✓
DATA FROM P/L N SYSTEMS				✓		P	P		✓

P = PARTIAL

Figure 5-2. Top Level Protocol Table

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DECISION FUNCTIONS	PLACE WHERE DECISION IS MADE			
	GROUND	SPACE PLATFORM	MEC SUBSYSTEM	MEC PAYLOADS
DECISIONS REGARDING ELECTRIC POWER				
• Select buses to be activated		✓		
• Allocate priority buses to SP payloads		✓		
• Modify bus allocation to MEC		✓		
• Distribute allocated buses and power to MEC payloads			✓	
• Control transfer of power to MEC payloads			✓	
• Recognize bus/power configuration changes imposed by SP			✓	
• Control transfer of power within payload				✓
• Condition allocated payload bus supplies				✓
DECISIONS REGARDING DATA MANAGEMENT				
• Generate payload houskeeping data				✓
• Generate payload bus/load profile data				✓
• Use data for on-board decisions			✓	
• Condition/store data				✓
• Request data downlink	✓			
• Provide downlink capability	✓	✓		
• Transmit data		✓		
DECISIONS REGARDING COMMAND FUNCTIONS				
• Generate SP commands	✓	✓		
• Route SP commands		✓		
• Generate MEC commands	✓	✓	✓	
• Route MEC commands			✓	
• Generate payload commands	✓		✓	✓
• Receive/verify/decode commands		✓	✓	
• Store high rate data			✓	✓

Figure 5-3. MEC Mission Decision-Making Assignments Matrix

5.3 ELECTRICAL POWER DISTRIBUTION SUBSYSTEM (EPDS)

5.3.1 EPDS Functions and Requirements

EPDS functions and design requirements are listed as follows:

1. Interface with SP during free-flying and sortie modes, with Orbiter during ascent and retrieval.
2. Distribute and control main power buses (3 @ 30 VDC, 2 @ 120 VDC) to all payload ports.
3. Provide and control deadfacing switches for all power buses at all payload ports.
4. Support MEC and payload minimum housekeeping loads through non-interrupted priority bus.
5. Provide stay-alive power to MEC subsystems and payloads by a rechargeable battery when no power available from other sources, e.g., prior to SP power switch turn-on.
6. Provide protection against overloads (payloads, MEC subsystems).

Requirements for initial and all-up MEC differ primarily in power level supplied and number of payloads accommodated.

5.3.2 Design Approach

Key issues in EPDS design are summarized below:

- Payload and housekeeping load profiles, power budgets
- Power allocation protocol
- Voltage levels and power form supplied to users
- Bus redundancy, intertie switching
- Safety requirements and deadfacing implementation
- SP and Orbiter interface implementation, EMI constraints

The EPDS design approach accordingly is based on the following principal considerations:

1. Growth from initial to all-up MEC primarily involves power level and number of payloads accommodated.
2. EPDS functions are essentially similar.
3. Payloads provide own individual power conditioning if SP-provided voltage levels and quality of voltage regulation are insufficient.
4. MEC will provide central power management system to control system health and maximize source power utilization.
5. Payload power interfaces are standardized as much as feasible.
6. Effective CDMS utilization is provided by the power distribution and control design.

5.3.3 EPDS Concept

Figure 5-4 shows a block diagram of the selected SP/MEC/payload power distribution and control concept including MEC/SP and the MEC/payload interfaces. System design features and operating characteristics are summarized as follows:

1. MEC distributes SP power by connecting an identical set of high voltage (120 VDC) and low voltage (30 VDC) power buses at a nominal power capacity of 12.5 kW to each of the payloads. How much power is consumed in each case depends on the specific payload design and on allocations made.
2. MEC provides power distribution, conditioning, regulation and protection for its own subsystems.
3. Each payload is supplied with 30 VDC, 120 VDC, 30 VDC essential bus and optionally 220 VAC, 3 phase 400 Hz power. MEC provides no power conditioning and regulation for payloads beyond $\pm$ 1% at the 120 V and 30 V voltage levels supplied by the SP. The payloads perform power conditioning and regulation beyond the $\pm$ 1% provided by the SP as required.
4. Power ports are arranged to provide flexibility in allocating power to payloads. Each payload may utilize one, two or three power ports.
5. All power lines are controlled and deadfaced on the MEC side of the MEC/payload interfaces.
6. All port power lines are load monitored by the CDMS to provide resource sharing or load shedding as may be required. Load monitoring is backed up with circuit breakers and fuses in each line.
7. The 30 VDC essential bus is backed up by batteries when SP or Orbiter power is not available. This bus is disconnected last and reconnected first, via a separate deadfacing command from the SP.
8. Each payload uses nominally up to 12.5 kW (initial MEC) at a level and sequence predetermined by mission protocol under its own power distribution and load control, monitored by MEC. The payloads provide their own overload power protection. They provide and maintain electrical isolation for the power buses utilized by them.

In performing the programmed normal operating profile, MEC will monitor all buses to all payloads. If an incorrect power profile use is determined, MEC will command the bus switches to the respective payload(s) to "off." It thus provides a redunant control function to the payload's internal monitoring/protection system to avert the more serious effect of SP-originated load shedding.

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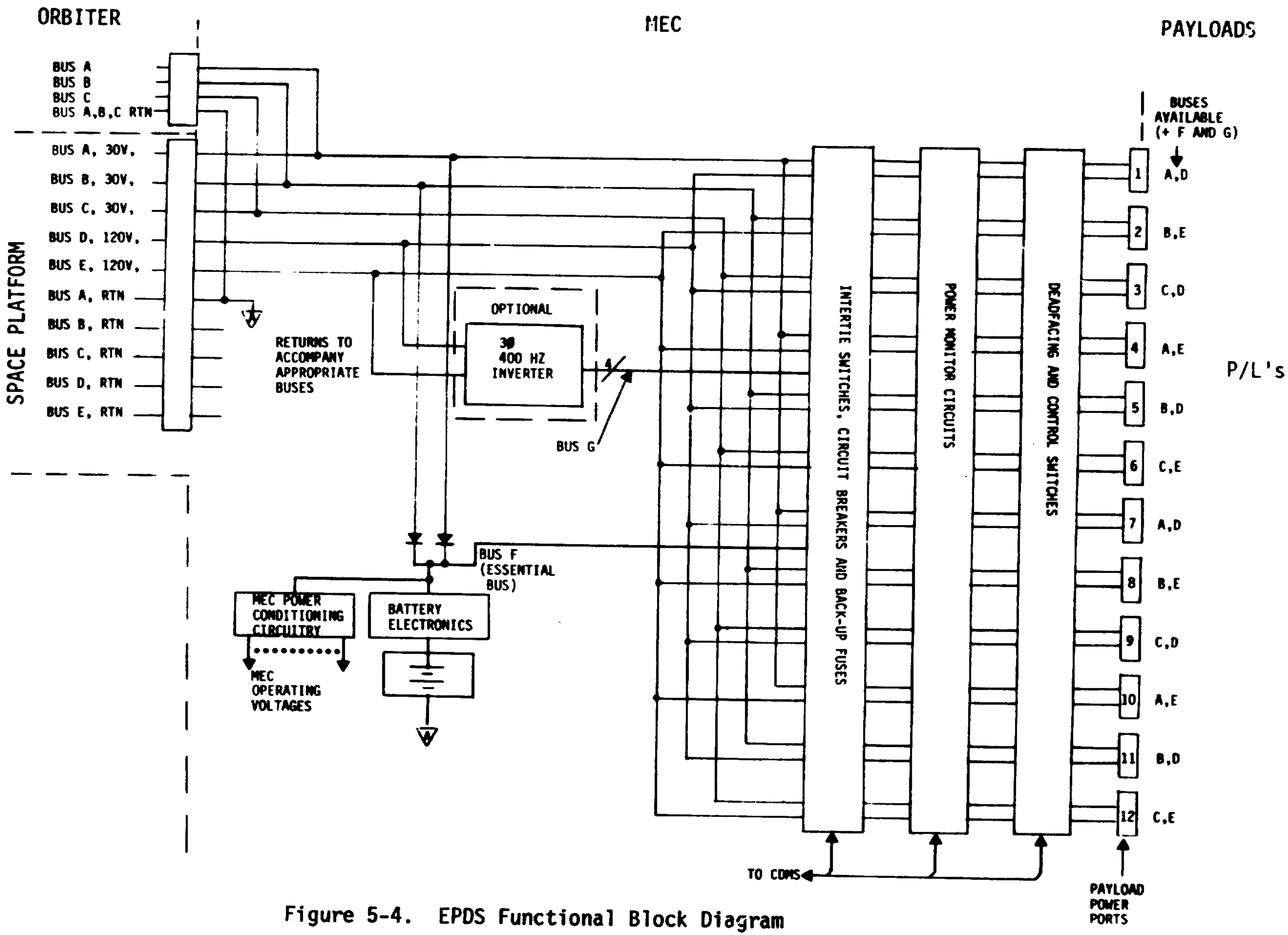

Figure 5-4. EPDS Functional Block Diagram

5.3.4 EPDS Transition To All-Up MEC

EPDS growth to all-up MEC capability will primarily require additional cabling, added power control switches and increased auxiliary battery capacity to accommodate the added payload ports.

Referring to the all-up configuration shown in Figure 4-12 it also is apparent that extra cable length is required to convert the subsystem compartment in the MEC core module to the Space Platform interface adatper via the utility duct in the MEC growth module.

While power distribution cables to each payload port in the core module will be sized for 12.5 kW maximum payload power requirements, those to growth module payload ports will provide up to 25 kW to meet maximum power requirements of unique payloads carried in the all-up MEC.

Payload requirements determined in Section 2 and Reference 5 indicate that some payloads, e.g., float zone processing and high gradient solidification systems to be carried on all-up MEC missions, may require 25 kW or more of maximum processing power. This would of course imply a power allocation sequence that temporarily shuts off power to other MEC or Space Platform payloads. Current estimates of the maximum power levels to be supplied to payloads of the SP growth version indicate an upper limit of 35 to 40 kW, dictated by design economy rather than by the maximum average solar power available during favorable (short or no-eclipse) seasons. For further discussion of all-up MEC maximum power capacity and power utilization see Section 5.3.5.

5.3.5 Power Utilization Trades

MEC power utilization is governed by the total payload power available from the host vehicle, i.e., the initial or all-up Space Platform, less the power allocated to other SP users. In general, payloads carried by the initial or all-up MEC demand more than the allocated share of SP power, and some time-sharing will often be necessary, as exemplified by the power profile shown in Figure 4-15.

A trade between payload power requirements and the maximum power capacity to be provided by MEC is required which also must take into account MEC and SP heat rejection capabilities. The anticipated SP heat dissipation capacity,

11 kW for the initial SP and 22.5 kW for the growth version, imposes an upper limit on total MEC power utilization unless an auxiliary MEC radiator is provided. With the concurrence of the MSFC MEC Project Office it was concluded that the initial MEC design should not include an auxiliary radiator, thus limiting its power utilization capacity to 12.5 kW. The all-up MEC design might include a deployable radiator if the amount of extra SP power above 25 kW occasionally allocated for MEC use warrants the added design complexity and expense.

Estimated SP power levels summarized in Table 5-3 are relevant to this analysis. Listed are representative EOL solar array output power levels of the 12.5 kW and 25 kW Space Platform designs, average power outputs for maximum and low eclipse durations and the estimated power available for payload use.* It is apparent that even for short eclipse durations the payload power does not increase above 15 kW for the 12.5 kW SP and above 32 kW for the 25 kW SP design assumed here, due to regulator output capacity limits that are dictated by SP design/cost effectiveness considerations.

Also of concern is the fact that seasonal SP power increments above the nominal level occur with a frequency that is inversely realted to magnitude. Figure 5-5 shows typical 25 kW Space Platform power output profiles derived from a recent SASP study by TRW, Reference 15. (These profiles do not reflect the SP regulator output limit mentioned before). Minor power maxima occur at 20 to 30 day intervals both at high and low orbit inclinations. In the case of 57 deg inclination the profile also shows major power peaks which occur at 70 to 100 day intervals and with 10 to 15 day duration.

Figure 5-6 displays this information in terms of the incidence of increased SP power output above the nominal 25 kW level, expressed as time fraction F per year vs. total power output. The three curves shown on the right represent these time fractions for orbits of 28.5, 57 and 90 deg inclination. The parametric plot on the left indicates the net time fraction F_M of increased power available to MEC versus the share S_M of total SP output power that is allocated to MEC, F_M being the product of S_M (abscissa) and F (ordinate). The parameter lines are lines of constant F_M values. The two examples shown for 32 kW total power (Δ=7kW) and 75 percent MEC power

*The data presented in this table do not reflect any specific characteristics of the current SP designs by TRW or McDonnell Douglas which are unavailable at this time.

Table 5-3. Estimated Space Platform Power Levels at EOS (kW)*

ECLIPSE DURATION (PERCENT)	12.5 kW SP			25 kW SP		
	40 (1)	30	20	40 (1)	30	20
1. Net Solar Array Output	31.0	31.0	31.0	62.0	62.0	62.0
2. Average Power Output (2)	15.5	19.0	22.8	31.0	38.0	45.6
3. Power Output of Regulator (3)	15.5	18.0	18.0	31.0	38.0	38.0
4. Housekeeping Power (including misc. losses) (4)	3.0	3.0	3.0	6.0	6.0	6.0
5. Maximum Power to Payloads (5)	12.5	15.0	15.0	25.0	32.0	32.0

NOTES:

(1) Maximum eclipse duration in 200 n.m., 28.5 deg SP orbit

(2) For representative battery charge/discharge and processing losses

(3) Limited by regulator capacity

(4) Estimated values

(5) Limited by regulator output capacity if eclipse duration $\leq$ 30 percent.

*The data in this table are best estimates. They do not reflect any specific characteristics of current Space Platform designs by TRW or McDonnell Douglas which are unavailable at this time.

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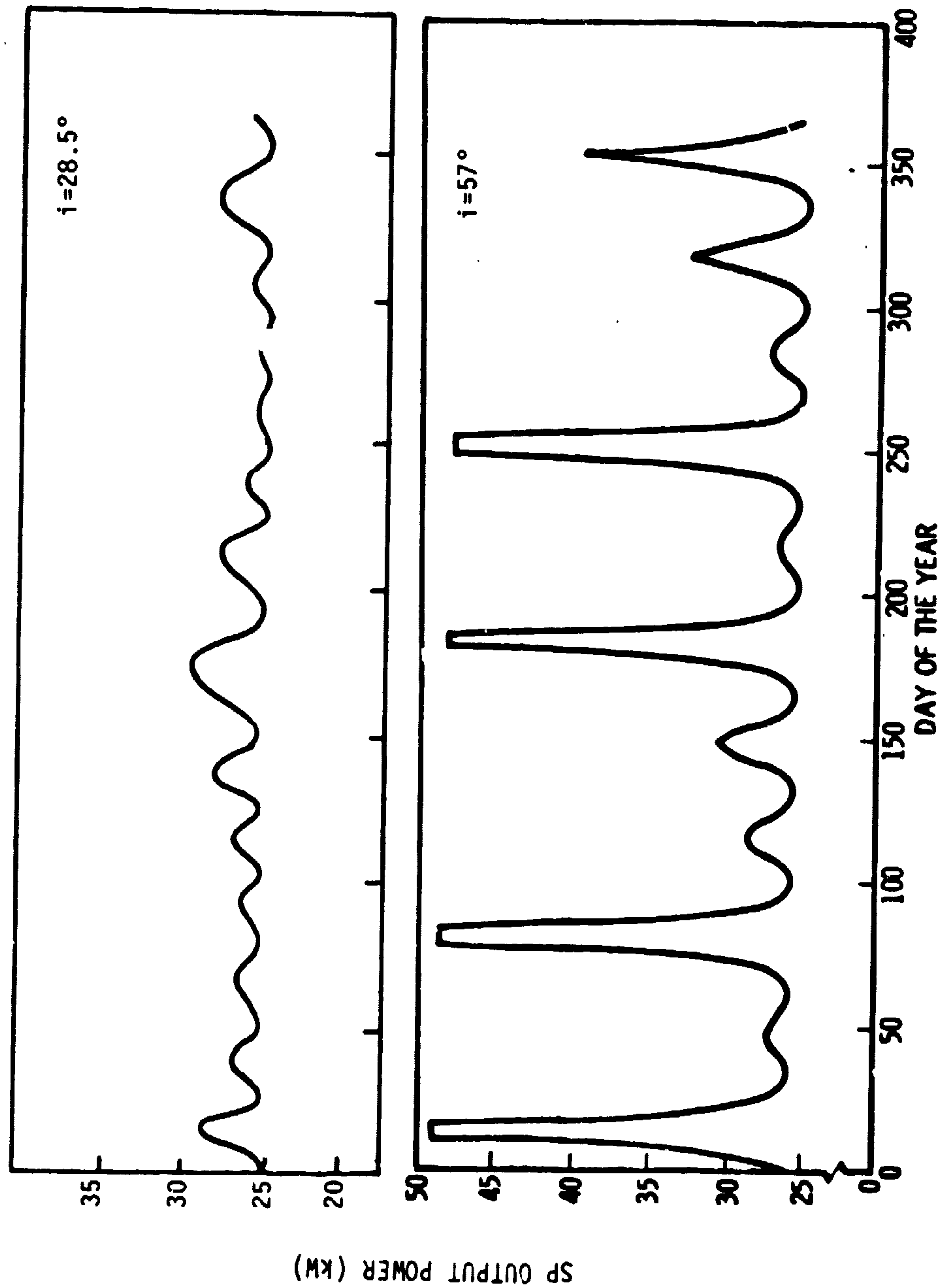

Figure 5-5. Typical SP Power Output Profiles at EOS for Low and Intermediate Orbit Inclination (Altitude 235 n.m.)

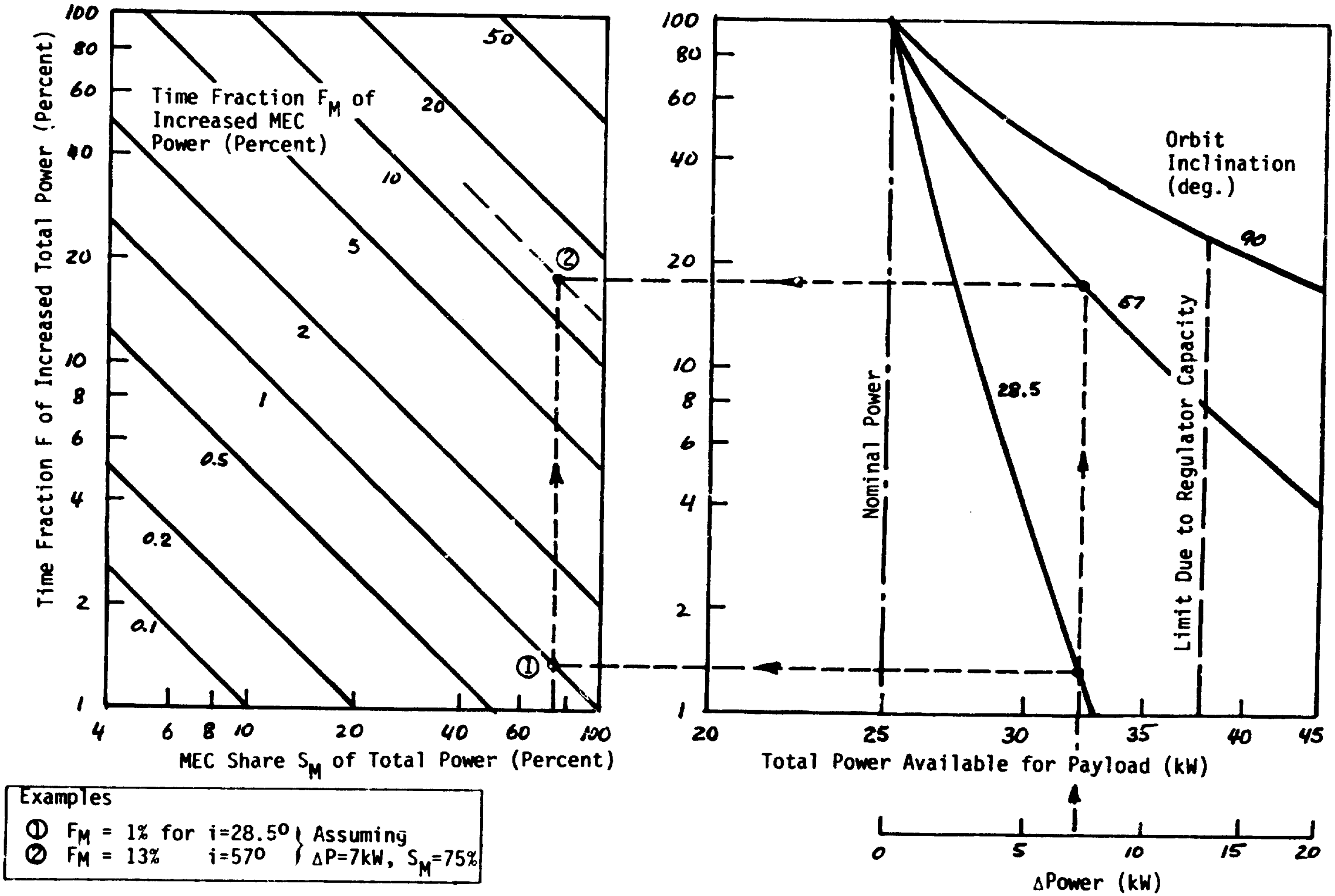

Figure 5-6. Time Fraction of Seasonal SP Extra Power Output

allocation indicate net time fractions F_M of only 1 percent, for a 28.5 deg orbit, and 13 percent for a 57 deg orbit. Higher power increments occur at correspondingly lower time fractions, as indicated by the steep decline of the two curves in questions, with a cutoff point determined by the SP regulator limit (assumed to be 37.5 kW).

Results of this analysis lead to the following conclusions regarding maximum power capacity of the initial and all-up MEC design:

1. With MEC payloads generally demanding the maximum amount of SP output power available at any time, the MEC EPDS circuits should be designed to accommodate total power levels somewhat higher than the nominal SP output power.
2. A limiting factor is MEC heat rejection capacity which will be the same as the maximum SP heat rejection capacity via the heat exchanger assigned to the MEC berthing port, unless it is augmented by a MEC auxiliary radiator.
3. The initial MEC will not carry an auxiliary radiator, because of the low probability of being able to obtain all or more of the nominal 12.5 kW SP power output at any time. The EPDS circuits will be designed for this maximum power level for the 12.5 kW SP
4. The all-up MEC generally will not carry an auxiliary radiator, for the same reasons, but its design will be scarred for addition of a radiator in missions where extra power would be essential to meet unique MEC payload requirements.
5. All-up MEC power distribution design will be compat with this extra power utilization at little or no increase in EPDS design complexity as cabling to each growth module payload port will be rated for 25 kW maximum power.

These conclusions should be re-examined and updated, if necessary, at the time when SP maximum power output, heat rejection capacity, MEC payload power requirements and mission profiles will be more firmly established.

5.4 COMMAND AND DATA MANAGEMENT (CDMS)

5.4.1 CDMS Functions and Requirements

The CDMS will perform the functions and meet design requirements listed below. It will

1. Interface with the SP during free-flying and sortie modes, with the Orbiter during ascent and retrieval.
2. Distribute incoming and stored commands to individual payloads and to MEC engineering subsystems.

3. Acquire and manage all state-of-health, housekeeping and instrumentation data from payloads and MEC subsystem and store as required.
4. Format all data for transmission to the SP CDMS and/or communication subsystem or to the interfacing Orbiter CDMS/telemetry subsystem.
5. Monitor and provide executive control of MEC and MEC payloads.
6. Perform MEC and MEC payload verification and checkout routines on command.
7. Provide flexibility for selecting alternate sequences and reprogramming of CDMS executive software in response to incoming commands.
8. In the all-up MEC, perform fault detection, diagnostics and possibly fault correction functions (thus providing future MEC growth capability).
9. Also in future MEC operations it will provide artificial intelligence required to minimize ground-based, interactive control (e.g., to detect/correct faulty processing products).

5.4.2 Design Approach

Key issues in CDMS design are summarized below:

- Basic CDMS architecture must be consistent with modular growth to accommodate MEC evolution from initial to all-up version
- Reliance on interactive ground control for non-routine commands and on payload self-contained sequencing/process control capability in initial and all-up MEC
- CDMS control of the electrical power distribution and the thermal control subsystem
- Utilization of existing or planned hardware elements (e.g., from Spacelab, MEA, DACS, ! S/SL, SASP pallet, SP CDMS) for CDMS where feasible, to save cost
- Ease of in-orbit computer reprogramming, by ground command, of MEC operating sequences, payload processing operations and parameters.

The CDMS design approach accordingly is based on principal considerations such as the following:

1. A CDMS architecture is selected that permits initial MEC simplicity without limiting growth to all-up MEC capability.
2. A central processor (CPU) based I/O scheme controls the command and data flow, electrical power allocation and thermal subsystem.
3. Later addition of computer and mass memory extends MEC versatility and functional autonomy.

4. Use is made of MEA-C existing equipment designs where applicable (e.g., DACS).
5. Video data handling/processing capability is introduced in the all-up MEC for payloads requiring image data transmission to POCC.

5.4.3 CDMS Concept

The CDMS design (see block diagram Figure 5-7) is microprocessor-based to provide flexibility of data management and ease of conversion to the all-up MEC configuration. Figure 5-8 shows a block diagram of the CDMS computer. The selected computer is the DACS system used on MEA. The DACS is an 8080 based 8-bit computer. The incoming commands and outgoing data (from and to the SP) are in a serial data stream. A serial-to-parallel-to-serial interface converts the serial commands and data to parallel form usable by the computer. All incoming commands are intercepted by the computer for distribution to the payloads.

5.4.3.1 Command Distribution

Command distribution may be immediate or deferred in accordance with information received with the command. The data links to the payload RAU's are also serial so the commands from the computer must be converted back to serial form prior to distribution.

Provision is also made for issuance of commands stored in command tables. The tables can exist either in read-only memory (ROM) firmware, the read-write memory (RAM) or a combination of the two.

All commands are echoed back to the SP to verify their receipt. Along with the echoed command information is provided to indicate the command was accepted (allowable command) and processed.

5.4.3.2 Data Handling

All outgoing data must be packetized. The computer therefore collects all data from payloads and organizes them into packets before sending these to the SP.

There are also commands and data associated with the MEC itself. These are treated in the same manner as payload commands and data.

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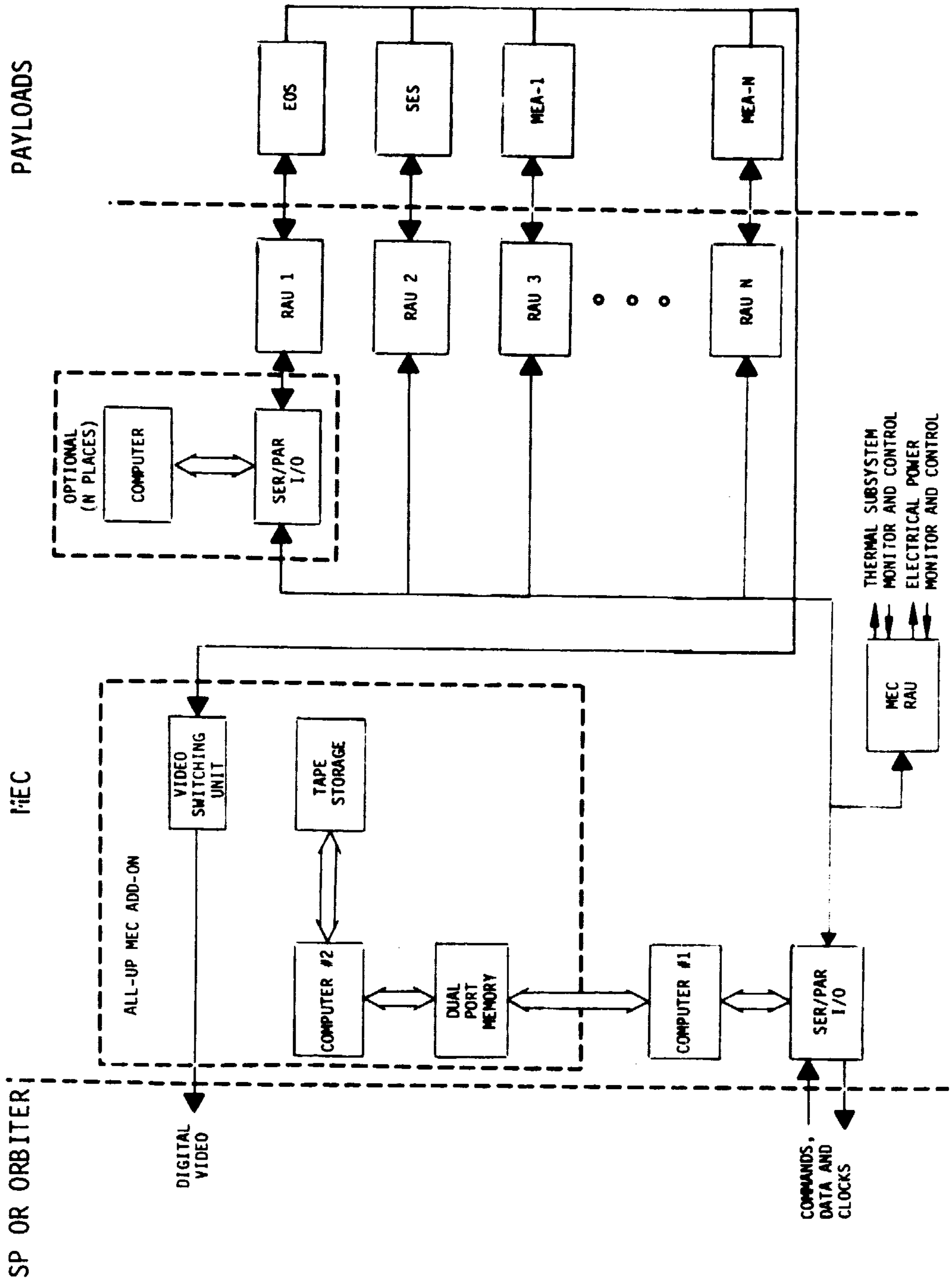

Figure 5-7. CDMS Functional Block Diagram

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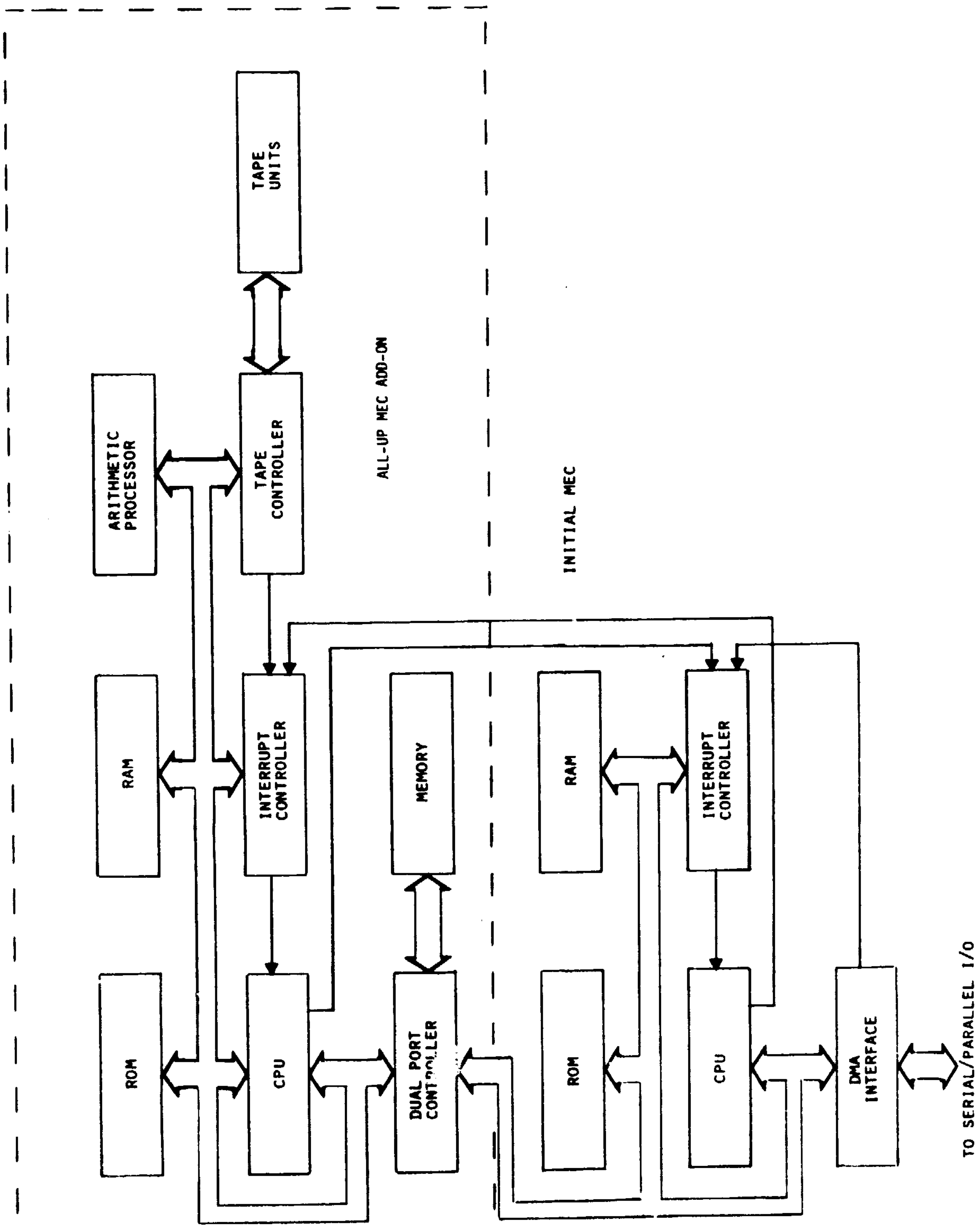

Figure 5-8. CDMS Computer System Block Diagram

The MEC thermal and power subsystems are controlled by the computer via the MEC RAU. Currents, voltages, temperatures and pressures are measured and used for control purposes and also sent out (via SP) as data.

Although not indicated in the CDMS block diagram (Figure 5-7), timing signals (clocks and GMT) and status information are passed across the MEC/SP data interface. These timing signals are in turn passed along to the payloads.

Full RAU capability is not neeaed for the payloads since all payload/MEC interface data is in serial digital form. For example, the AD converter function is not needed. Therefore, the design will use minimum configuration RAU's which have only the capability required.

5.4.3.3 Computer Growth Capability

Although the initial MEC CDMS does have a limited computational capability by virtue of its microprocessor-based computer this capability may prove inadequate for the all-up MEC configuration. For this reason provision has been made to add a second computer to provide the required growth capability. The list of candidate add-on computers ranges from 8-bit machines such as the DACS to the 32-bit iAPX432. The data path to the add-on computer will be through a dual port memory. This is simply a read-write memory that both computers have access to. It provides the means of passing parameters and instructions between the computers.

The computer interconnections are shown in the CDMS computer system Block Diagram (Figure 5-8). The add-on computer contains a hardware arithmetic processor. This will greatly increase computational throughput over a purely software computational approach depending on the CPU chosen. Also the capability for mass storage (tape) has been added.

No video image data capability is included in the initial MEC but it is planned for the all-up MEC.

5.4.3.4 Software and Reprogramming Issues

Two possible methods of structuring the software for ease of modification and reprogramming are shown in Figures 5-9 and 5-10. These are by no means the only possible ways to accomplish the task but are intended to serve as examples. Both methods assume a permanent copy of the original version of the system program exists in ROM.

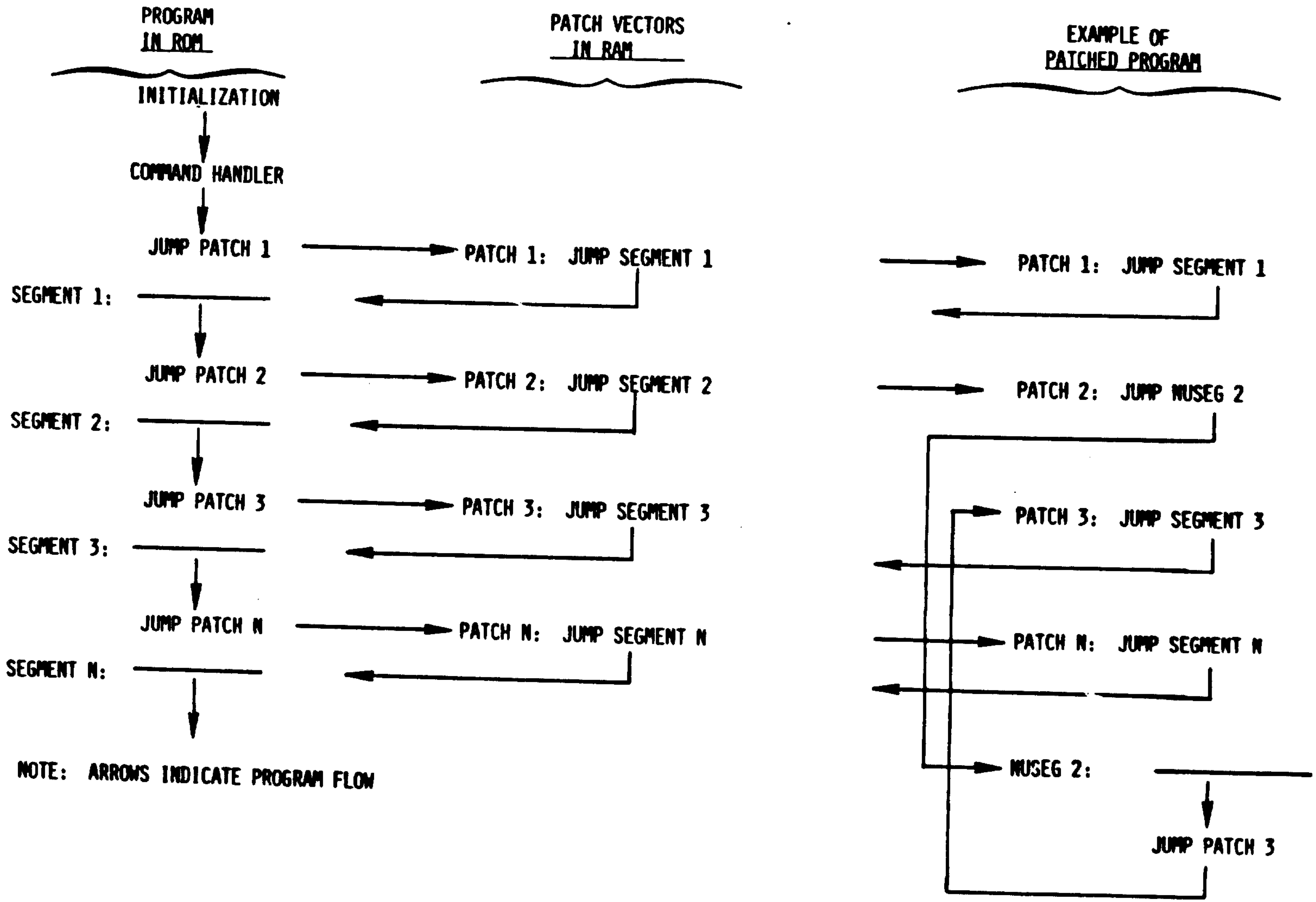

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Figure 5-9. Alternate Program Structure for Ease of Program Modification

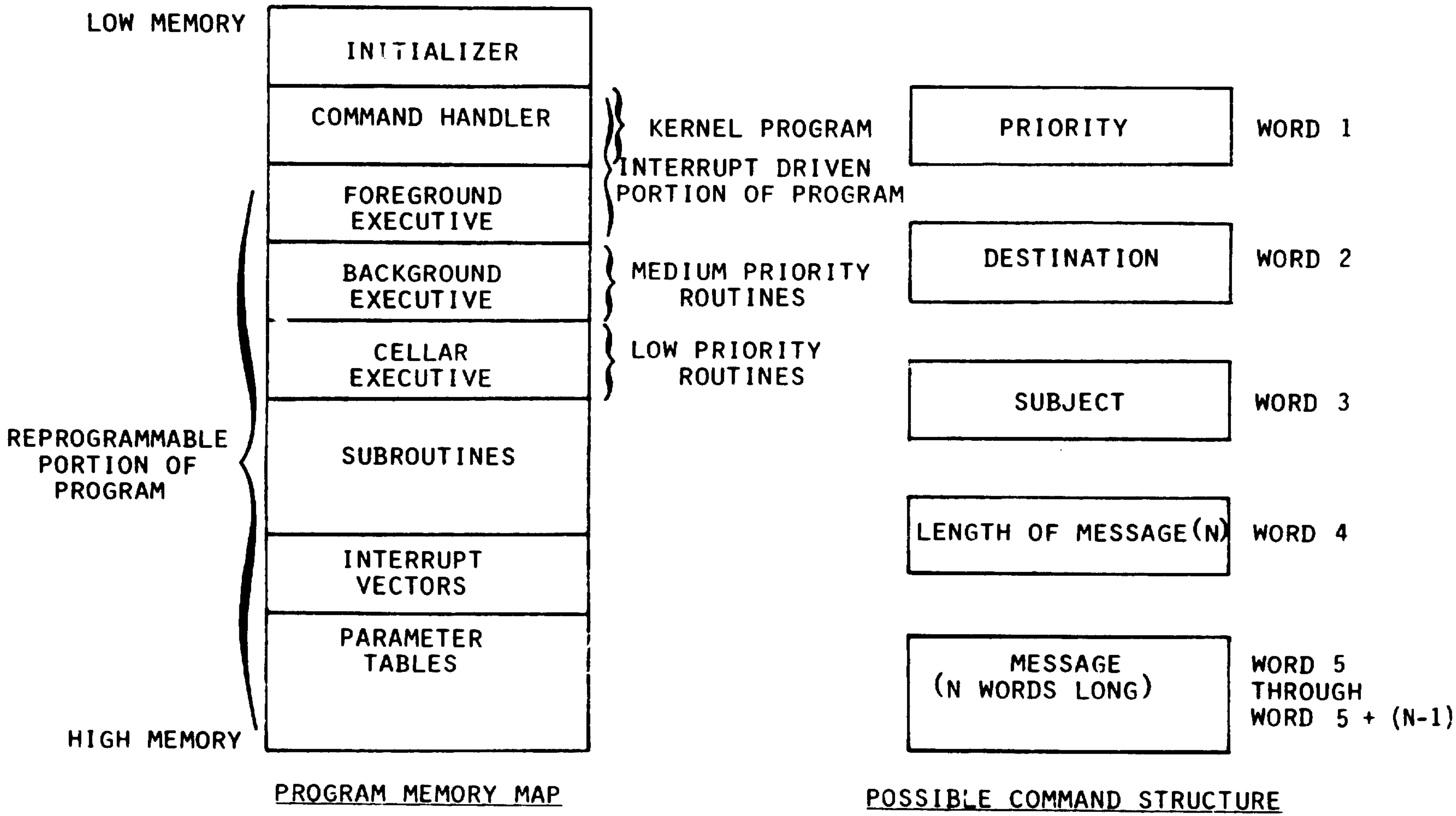

Figure 5-10. Program and Command Structures for Ease of Program Modification

The first method moves the entire program to the read-write memory (RAM) during system initialization (power-on startup). The program can then be altered upon command as desired.

Care must be taken so the kernel portion of the program is not altered. Alteration of the kernel could destroy the command handler resulting in loss of all communication with MEC. Recovery is possible even then by having SP execute the reinitialization process. However, the initial program would now be in RAM and any changes previously made would have to be redone.

Figure 5-10 shows a map of the program memory elements (left side) and a typical command structure (right side) containing a total of 5+(N-1) words for an N-word message. The program and command structure are designed to facilitate on-orbit program modification. In this concept, assignment of message priority levels in commands received prevents interrupts from being honored while the program is being changed. This precaution is necessary because an interrupt-driven portion of the program may be undergoing alteration. For true ease of reprogramming the software must be designed to be easily modified and maintained.

The second method (see Figure 5-9) leaves the original program in the ROM but causes patch vectors or "hooks" to be written into RAM upon initialization. Until altered the patch vectors act as "no-operation" or "continue" statements. New program segments can be written into RAM (upon commands) and the patch vectors altered to use new program segments in place of the originals. The original program can be segmented into as many small pieces as desired.

5.4.3.5 MEC Data Rates

Command and telemetry data rates required by MEC and its payloads vary over a wide range with payload composition and operating modes. Estimated maximum command rates for the initial MEC are about 0.5 Kbps. Scientific and housekeeping data rates may range from 12 to 17 kbps. These requirements are well below the SP/TDRSS forward link (10 Kbps) and return link (46 Kbps) channel capacities in the S-Band multiple access mode.

The low telemetry data rate requirements reflect time-shared payload operations, where only EOS, SES and one or two MEA facilities will be active simultaneously at any time. Elimination of imaging requirements in the

initial MEC also is a key factor in holding telemetry bit rates to a low level.

For data rate requirements of the all-up MEC reference is made to results of the payload analysis conducted in MEC Study, Part 1 (Final Report, Volume III, Sections 4.6.2 and 5.6). Maximum command rates were estimated as about 1 Kbps. Telemetry rates, including those for multiple image system outputs, increase to several Mbps, thus requiring using a TDRSS link, K_u-band, single-access channel. Still these requirements are minor compared with projected maximum SP/TDRSS channel capacities.

5.4.3.6 MEC End-To-End Data Flow

Figure 5-11A shows the data flow between the MEC and the payload users, e.g., principal investigators.

The diagram is intended to show how MEC commands are initiated, verified and intermixed with other SP commands and sent to the SP. The SP then distributes the commands to their proper destination.

In a similar fashion MEC and MEC payload data is packetized and sent to the SP where it is intermixed with other SP data and relayed to earth. The data is then sorted and distributed to the ultimate users.

5.5 THERMAL CONTROL SUBSYSTEM (TCS)

5.5.1 TCS Functions and Requirements

The thermal control subsystem must

1. Efficiently collect all MEC and MEC payload waste heat and transfer it to the SP for dissipation through the SP radiator. This includes minimizing uncontrolled heat loss to space from payloads or from MEC.
2. Be capable of meeting all payload requirements (including those of MEA facilities, SES and EOS if possible), including inlet temperatures, flow rates and changes in payload status, active processing and pre-and post-processing.

Accommodation of EOS as MEC-attached rather than as independent payload, directly attached to SP is not a firm requirement. However, as discussed earlier, it will be advantageous to provide this capability in order to:

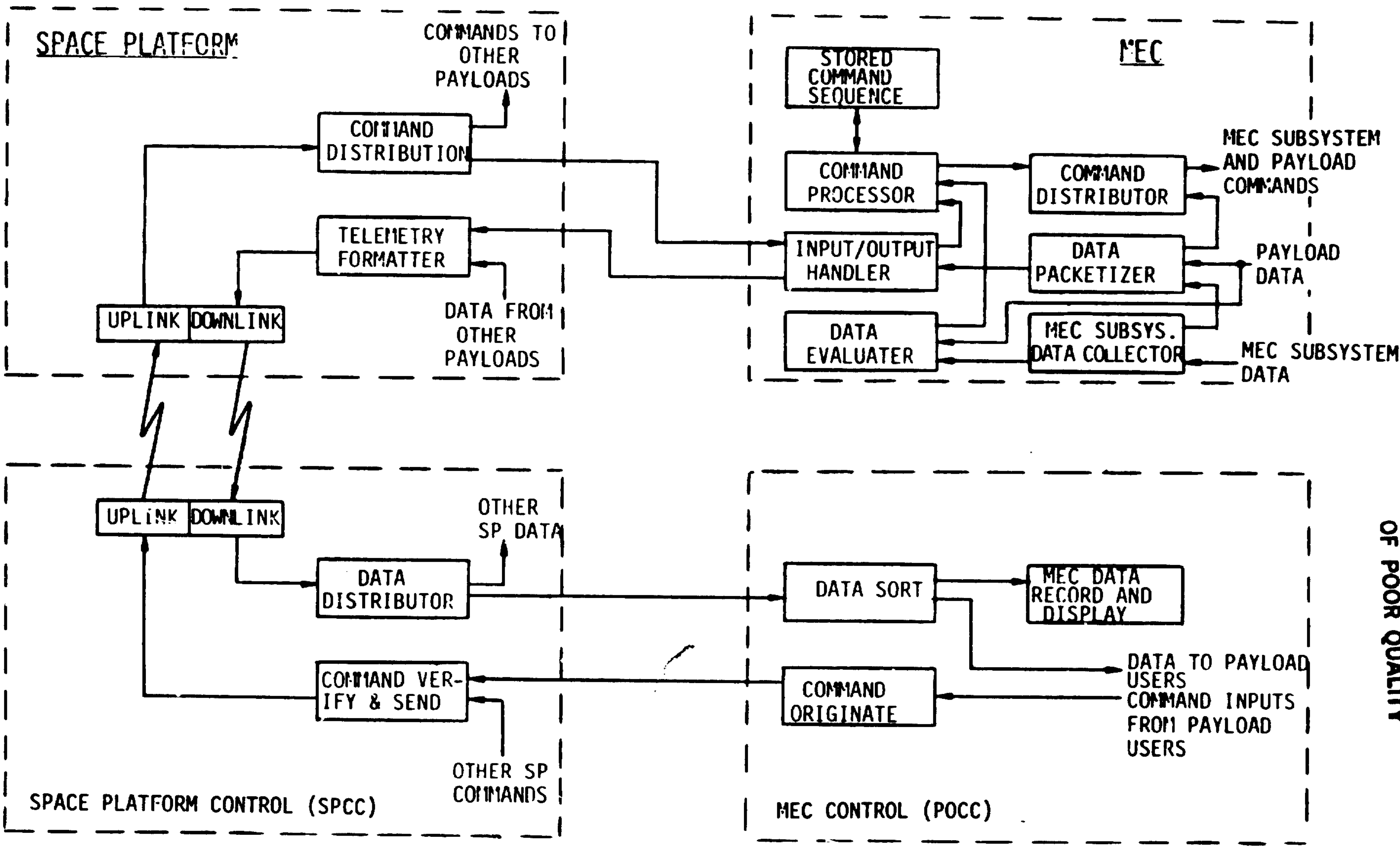

Figure 5-11A. MEC End-To-End Data Flow

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(a) Increase MEC utilization diversity, e.g., as a carrier of commercial-type payloads such as EOS

(b) Make available the extra berthing port (which would then not be occupied by the EOS) to other potential SP users

(c) Achieve greater MEC and SP mission flexibility, in general.

These programmatic advantages outweigh the extra cost imposed by EOS accommodation of increased MEC design complexity, particularly in terms of the TCS design. Results of the analysis presented in this section support this conclusion.

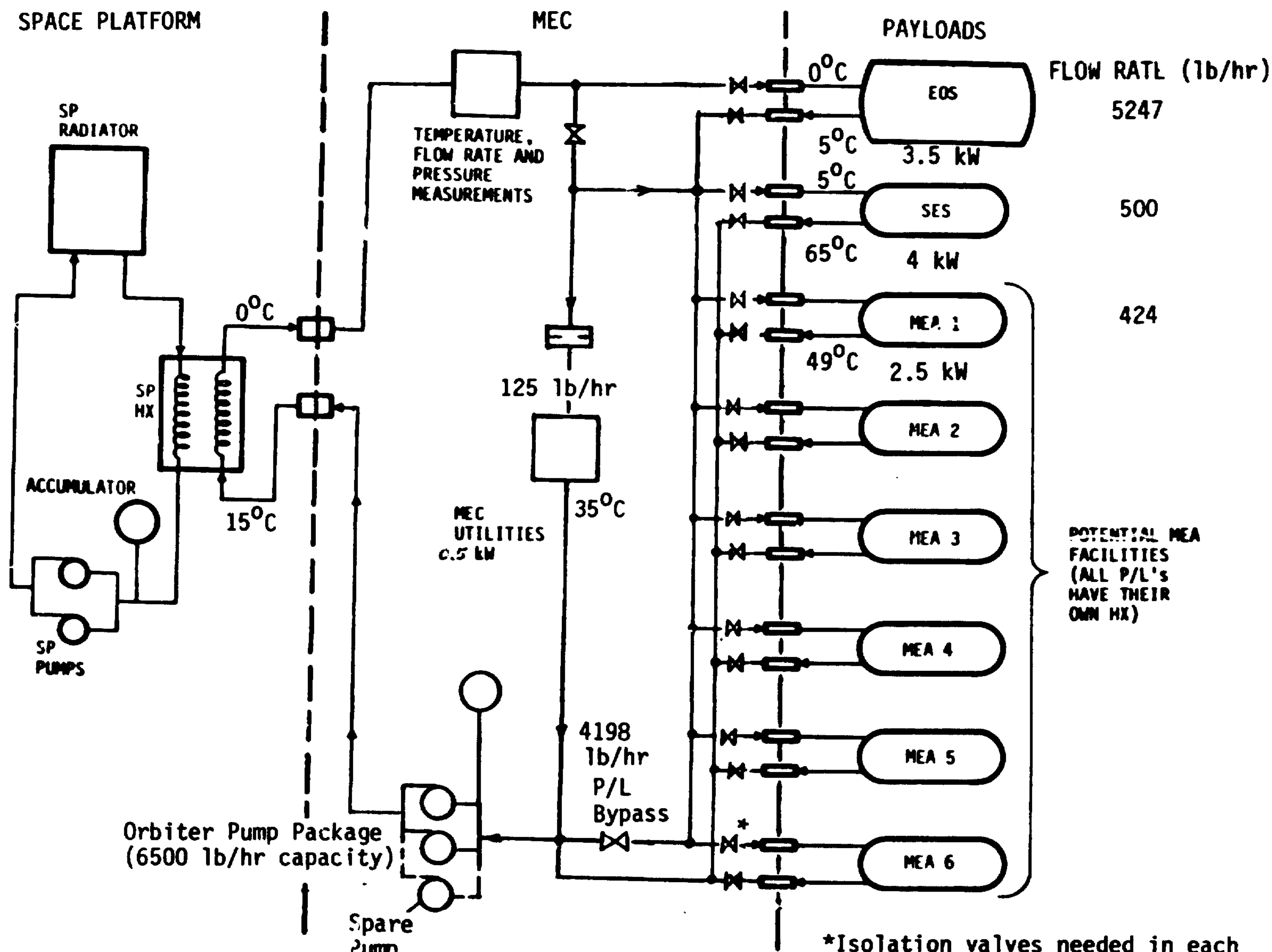
5.5.2 TCS Design Concept

Key TCS design issues are the following:

- Accommodation of large load profile variations due to payload operating cycles; payload interchange between or during mission; and diversity of payloads, in general
- Compatibility of fluid loop design with heat rejection requirements of extremely low and high temperature processes, e.g., those of EOS vs. furnace-type payloads
- Compatibility with functional and operational constraints imposed by the fluid loop/heat exchanger interface with the Space Platform TCS
- Safety, reliability and ease of manipulation, on orbit, of fluid loop quick disconnects at the MEC/SP interface (and also the MEC/payload interfaces designed for on-orbit payload changeout in the all-up MEC)
- Scarring the TCS design for possible addition of a MEC auxiliary radiator in missions where MEC heat rejection requirements exceed SP capabilities (see discussion in Section 5.3).

The selected TCS design concept is illustrated in Figure 5-11. Its principal characteristics are summarized as follows:

1. Both initial and all-up MEC thermal design accommodate EOS.
2. Safe, reliable, single fluid loop for heat transfer parallel and redundant pumps for increased reliability.
3. Parallel rather than series coolant flow through all payloads (except EOS) to accommodate diversity and variability of temperature ranges and flow rates.
4. TCS designed for maximum payload requirements during processing operations as well as in pre- and post-processing phases.
5. Freon 21 tentatively selected as coolant.
6. Adequate insulation between payloads, as required by individual payload characteristics.



*Isolation valves needed in each payload loop, for system leak protection.

Figure 5-11. MEC Thermal Control Diagram

7. Heat exchangers and flow control in each coolant loop branch on payload side of the interface, designed to payload-specific requirements.
8. MEC thermal control subsystem design approach uses elements of advanced MEA TCS design.
9. The selected TCS design concept for the initial MEC is adaptable to all-up MEC requirements, thus permitting easy and economical capability growth.

5.5.3 Block Diagram

The block diagram (Figure 5-11) shows the fluid loop configuration and interfaces with the SP and MEC payloads, including EOS, SES and MEA facilities. The SP thermal interface is at the heat exchanger assigned to the berthing port being used by MEC.

Heat transfer from MEC payloads is effected through heat exchangers on the payload side of the interface. Given the diversity and required interchangeability of payloads, the handling of payload-specific heat transfer requirements individually by each payload facilitates interface standardization.

Note, however, that this design concept is more vulnerable to leaks in the payload loops than the alternate one of placing the payload heat exchangers on the MEC side of the interface. In order to prevent leaks on the payload side or at interface connectors from disabling the MEC thermal control system, and thereby disrupting the entire mission, each payload loop in the selected configuration must be equipped with a pair of automatically controlled shut-off valves. The same valves also serve as individual coolant loop port isolation valves during checkout or servicing operations, or in MEC missions where some payload bays remain vacant.

Further study will be required to define appropriate, fast-acting and reliable valve control circuits and leak detectors. Local pressure sensors in each payload loop may be required for this purpose. The possibility of a low leak, not detectable by the sensors, causing a gradual coolant supply depletion also will have to addressed.

The greater flexibility of payload accommodation and TCS operation afforded by remote heat exchanger placement must be weighed against the increased design complexity of isolation valve and control circuitry addition required in this case. In this tradeoff the selected heat exchanger

placement shown in Figure 5-11 was found to be preferable to the alternative placement on the MEC side of the interface.

The fluid loop design is keyed to the large mass flow rate necessitated by performing EOS waste heat disposal at the specified very low heat exchanger outlet temperature of $5^{o}C$. With the inlet temperature constrained to a minimum of $0^{o}C$ the permissible inlet-to-orbit temperature difference is only $5^{o}C$. Thus, assuming 3.5 kW EOS waste heat and a specific heat of $C_p \cong 0.25 \frac{BTU}{lb \cdot {}^{o}F}$ ($=1.33 \times 10^{-4} \frac{kW \cdot sec}{lb \cdot {}^{o}C}$) for a Freon-type coolant, a mass flow rate of 5250 lb/hr will be required. Flow rates for other payloads usually are much smaller, especially in furnace-type processors where coolant loop inlet-to-outlet temperature differences would be an order of magnitude greater than those of EOS. Thus, several such payloads as well as MEC heat producing subsystem elements may be cooled by parallel fluid loops which are located downstream of the EOS loop as shown in Figure 5-11. This "hybrid" serial/parallel fluid loop configuration was selected for the initial as well as the all-up MEC TCS design. Its advantages compared with an all-serial or all-parallel configuration will be discussed in Section 5.5.4.3.

5.5.4 TCS Design Analysis and Trades

5.5.4.1 Design Concept Selection Rationale

Figure 5-12 shows the logic flow of the TCS design concept selection, based on the above discussion and on analyses and trades presented in the next subsections. The design issues addressed are listed on the left, reasons for making each selection on the right. Firm selections are indicated by boxes in heavy outline.

5.5.4.2 Coolant Temperatures

In the block diagram, Figure 5-11, coolant loops through all payloads except EOS were shown in a parallel flow arrangement. However, as previously discussed in Section 4 the limited power available from the SP in early MEC missions generally cannot accommodate more than two of these payloads at a time in addition to EOS. Alternate payloads will be turned on in a time-sharing sequence. Fluid loops to dormant payload units are assumed to be cut off in turn. The bypass valve shown at the bottom is provided to reduce coolant flow through the active loops thereby increasing their outlet temperatures to levels more compatible with the respective processors.

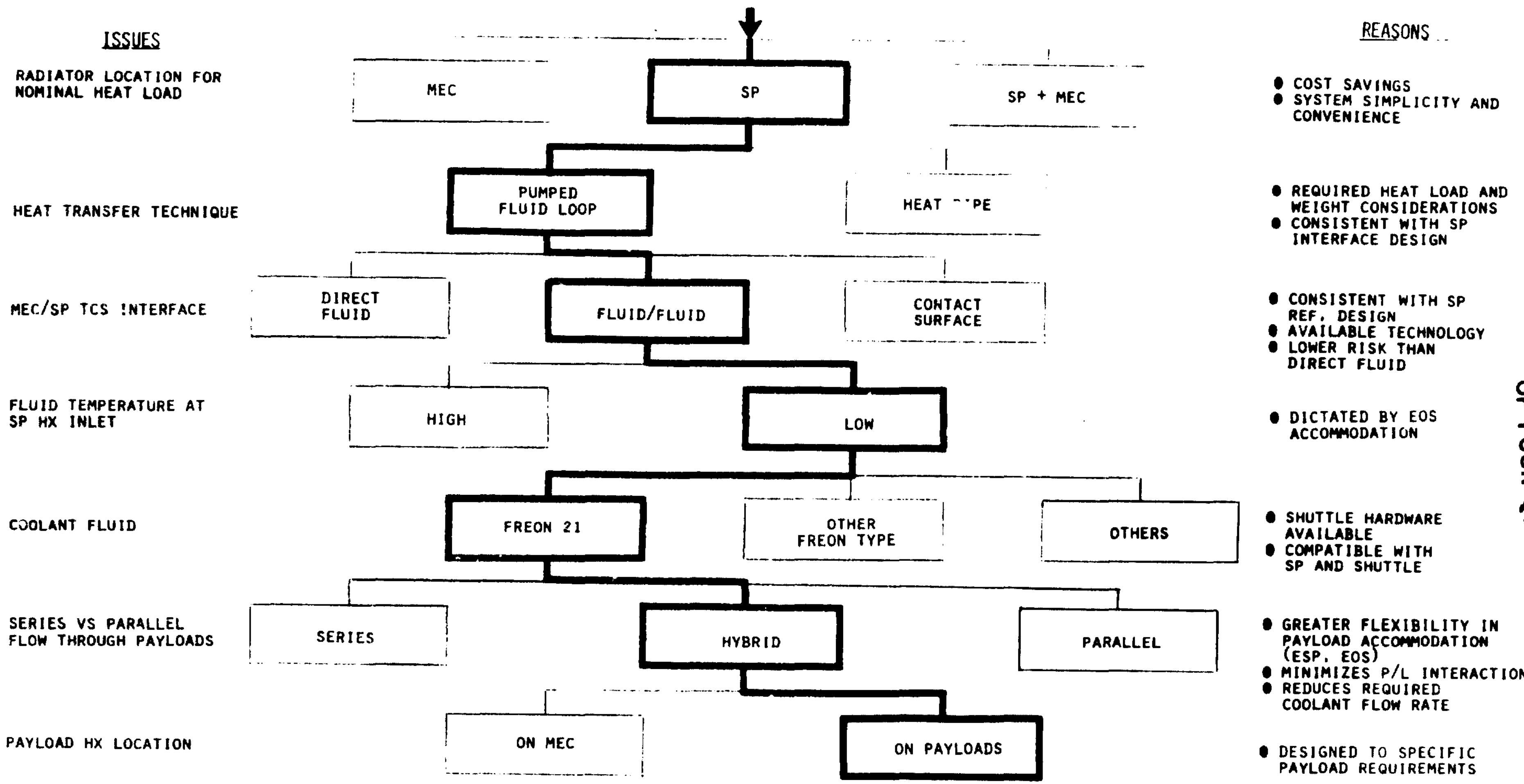


Figure 5-12. Thermal Control Selection

Tabld 5-4 lists flow rates and payload loop outlet temperatures corresponding to bypass flow rates of 70, 80 and 90 percent of the total. One SES and one MEA payload requiring 4.0 and 2.5 kW waste heat transfer, respectively, are assumed to be operating in addition to EOS. Results obtained for the 80 percent by-pass flow are those indicated in the TCS block diagram.

Raised coolant outlet temperatures will be desirable not only to enhance fluid loop/processor compatibility but also for increased efficiency of using an auxiliary MEC radiator in missions where SP heat rejection capacity needs augmentation (see Section 5.5.4.6).

5.5.4.3 Serial vs. Parallel Coolant Flow Concepts

Figure 5-13 schematically shows configurations with all-serial, all-parallel, and hybrid serial/parallel coolant flow and lists principal advantages and disadvantages of each.

The requirement of a very large flow rate dictated by the specified EOS temperature characteristics dominates the issue. The results would be quite different if EOS were to be eliminated as a MEC payload.

With EOS integrated into the system the comparison leads to the selection of the hybrid configuration as the preferred design. Principal factors are the lower total flow rate of the hybrid system compared with the all-parallel system, and easier adjustment to changes in payload composition or load profile (e.g., on-and-off cycles due to time sharing of SP resources) compared with the all-serial system.

5.5.4.4 Coolant Selection

Freon 21 was considered as first choice for use in the MEC TCS fluid loop, primarily becuase of compatibility with Shuttle Orbiter and Spacelab TCS hardware, and possibly also Space Platform hardware, that might be used in MEC development although the latter point cannot be confirmed at this time, pending MSFC definition of SP design characteristics.

Other Freon products, such as FC114, having a lower toxicity than Freon 21 and being more readily available on the domestic market, hence, less expensive, also are likely candidates for use in MEC.

Differences in the specific heat of Freon 21 (Cp=0.256) and FC 114 (Cp=0.243 BTU/lb·°F) are minor and affect the results presented in the preceding sections by only a few percent.

Table 5-4. Flow Rates and Coolant Temperatures in Serial/Parallel Fluid Loop

QUANTITY		HEAT REJECTION (kW)	CASE 1 BYPASS FLOW = 70%	CASE 2(1) 80%	CASE 3 90%
<u>Flow Rates</u> (LB/HR)					
EOS		3.5	5247	5247	5247
SES		4.0	750	500	250
MEA(2)		2.5	699	424	150
MEC S/S		0.5	125	125	125
Bypass		-	3673	4198	4722
<u>Temperatures</u> (^{o}C)					
EOS	IN		0	0	0
	OUT		5	5	5
SES	IN		5	5	5
	OUT		45	65	125
MEA	IN		5	5	5
	OUT		32	49	130
MEC S/S	IN		5	5	5
	OUT		35	35	35

Notes (1) These data used in TCS block diagram, Figure 5-11
(2) Only one MEA unit at a time allowed to operate

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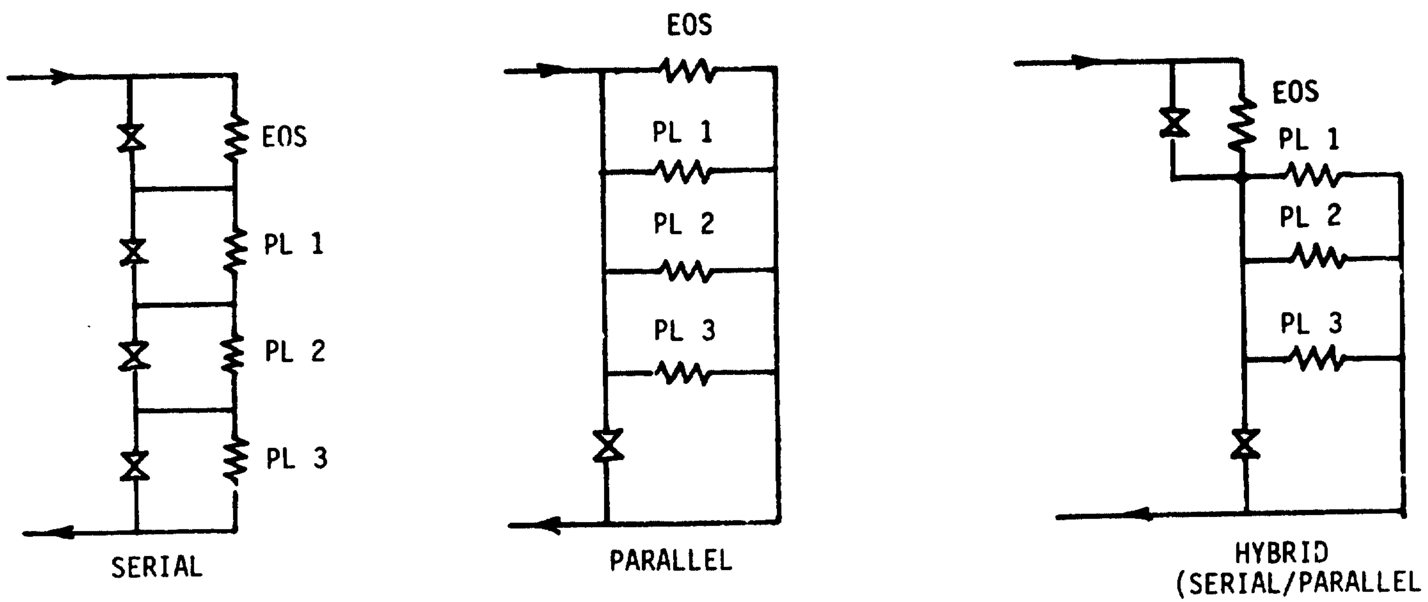


KEY ISSUES*

1 SERIAL	• Status change in P/L chain requires rebalancing. Control difficult. • Temperature of downstream payloads all very low. • N bypass loops
2 PARALLEL	• Requires greater coolant flow rate than 1 or 3 , may exceed dual pump capacity (6500 LB/HR) • One bypass loop (controls temperatures in PL 1, 2, 3) • Can use high temperature auxiliary radiator if necessary
3 HYBRID (SELECTED)	• Temperatures in P/L loops 1 to 3 easily controlled by bypass valve setting. • Flow rate same as in 1 less than 2 • Can use high temperature auxiliary radiator if necessary

*NOTE: Low EOS temperature dominates flow rates and temperatures in system

Figure 5-13. Serial, Parallel and Hybrid Fluid Loop Configurations

5.5.4.5 Transition to All-Up MEC

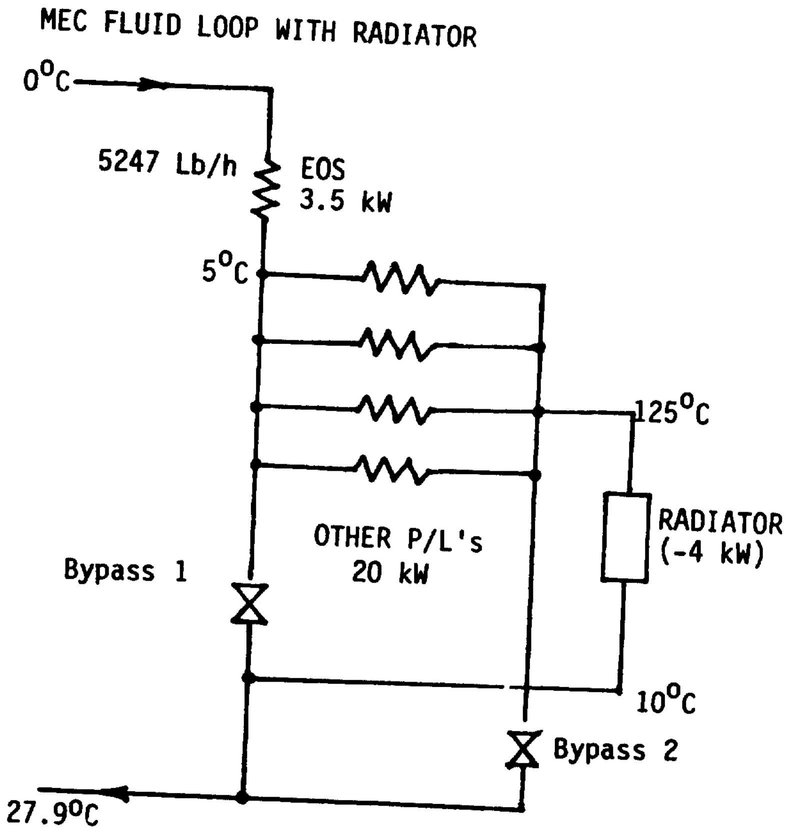
The TCS design shown in Figure 5-11 requires only minor modifications in the growth from initial to all-up MEC capability. The all-up MEC requires the addition of four payload fluid loops and interface equipment. The required pump capacity is dominated by EOS heat rejection requirements (flow rate 5250 lb/hr), both in the initial and all-up MEC. It is apparent that up to 10 all-up MEC payloads with average flow rate requirements of 500 lb/hr each could be readily accommodated by the selected serial/parallel fluid loop design without addition of another pump.

Actually, even in the all-up MEC some time-sharing of SP resources will be necessary. Thus, the 6500 lb/hr fluid loop pumping capacity of the initial MEC will provide an adequate growth margin for all-up MEC heat transfer requirements.

5.5.4.6 Addition of an Auxiliary Radiator in All-Up MEC

The selected TCS design permits addition of an auxiliary radiator with only minor changes of the basic fluid loop. As illustrated in Figure 5-14 the radiator fluid lines are connected at one end to the high temperature junction of the parallel payload loops, and at the other end to the pump assembly inlet, bypassing the direct fluid connection between those points. This arrangement permits the radiator to operate at an elevated temperature and, hence, higher heat rejection efficiency than the SP radiator. The objective is to limit the auxiliary radiator to a size that would permit wrap-around stowage against the MEC body. Referring to Figure 5-14 the radiator inlet temperature can be raised to the desired level by increasing the bypass flow rate from the EOS loop outlet junction, thereby reducing the flow through the hot payload fluid loops (see Section 5.5.4.2).

Figure 5-15 shows estimated MEC radiator sizes required for 3, 4 and 5 kW heat rejection versus radiator inlet temperature, assuming $10^{o}C$ outlet temperature. E.g., a 120 ft^2 MEC radiator operating at an inlet temperature of $125^{o}C$ will provide about 4 kW heat rejection, based on characteristics comparable to those of the SP radiator, a favorable viewing factor, and an orientation appropriate for edge-on sun illumination, parallel to the SP radiator.



COOLANT LOOP CHARACTERISTICS

COMPONENT	HEAT TRANSFER (kW)	FLOW RATE (LB/HR)	%	T_{IN} (°C)	T_{OUT} (°C)
EOS	3.5	5247	100	0	5
Other P/L's	20	1249	23.8	5	125
Bypass 1	-	3998	76.2	5	5
Bypass 2	-	(988)	(18.8)	125	125
Radiator	(-4)	(261)	(5.0)	125	10
MEC	19.5	5247	100	0	27.9

Figure 5-14. Fluid Loop With Auxiliary Radiator (All-Up MEC Only)

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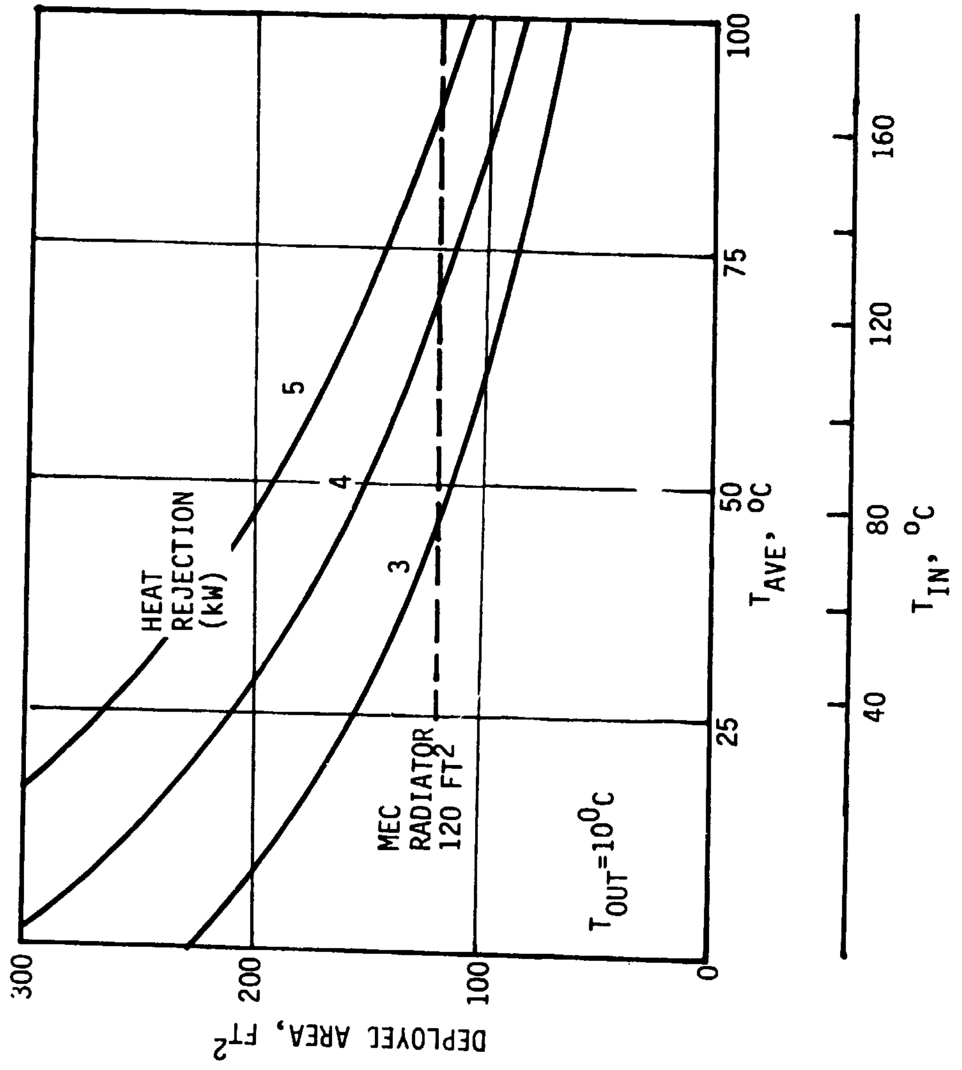

Figure 5-15. Auxiliary Radiator Heat Rejection Capacity

Figure 5-16 shows a deployable auxiliary MEC radiator sized for wrap-around stowage on one side of the MEC hull. In the deployed position it is parallel to the SP radiator. The radiator has five hinged active panels with a total area of about 120 ft^2. Deployment is by spring action controlled by two actuator-released restraint cables. These cables also serve to retract the radiator for re-stowage. Deployment and retraction is performed by remote control, but can be assisted by crew EVA if necessary. When deployed it does not restrict MEC payload access for servicing.

The sketch shows MEC attached at the SP x-port with the radiator extending in +z direction. As an alternative it may be attached to the z-port with the radiator extending in x direction. In either case, the radiator protrudes into the clearance volume of adjacent SP payloads. Also, MEC attachment at the +y or -y port would require modification of the deployment concept.

As an alternative to the concept illustrated in Figure 5-16 the use of body-mounted radiator panels attached to the payload compartment doors on both sides of the hull also was considered (Figure 5-17). The effective radiator area would be about the same as in the deployed case, but some of the panels would be periodically exposed to sun illumination causing a loss in overall heat rejection efficiency. This concept has the advantage of greater simplicity and avoids the problem of potential interference with adjacent SP payload clearance volumes.

Further study of these concepts should be deferred until a firm requirement for a MEC auxiliary radiator will be established.

5.6 STRUCTURE AND MECHANISMS SUBSYSTEM

5.6.1 Functions and Requirements

This subsystem will be designed to

1. Carry diversified payload complements including SES and MEA facilities (initial MEC configuration).
2. Carry additional larger payloads projected for all-up MEC missions.
3. Accommodate EOS as an added external payload (both in initial and all-up MEC missions).
4. Be compatible with Orbiter load environment, including maximum static, dynamic and acoustic loads.

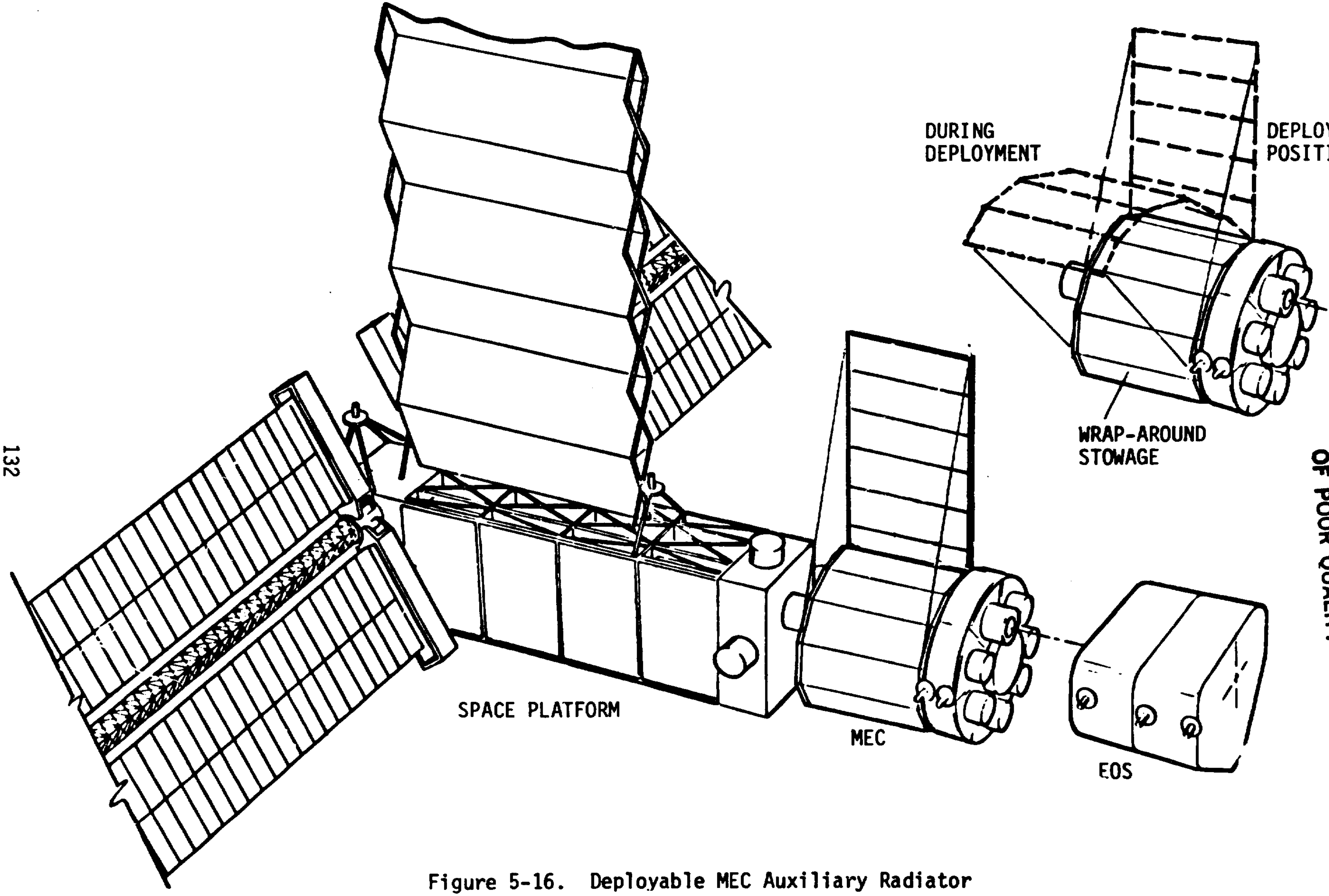

Figure 5-16. Deployable MEC Auxiliary Radiator

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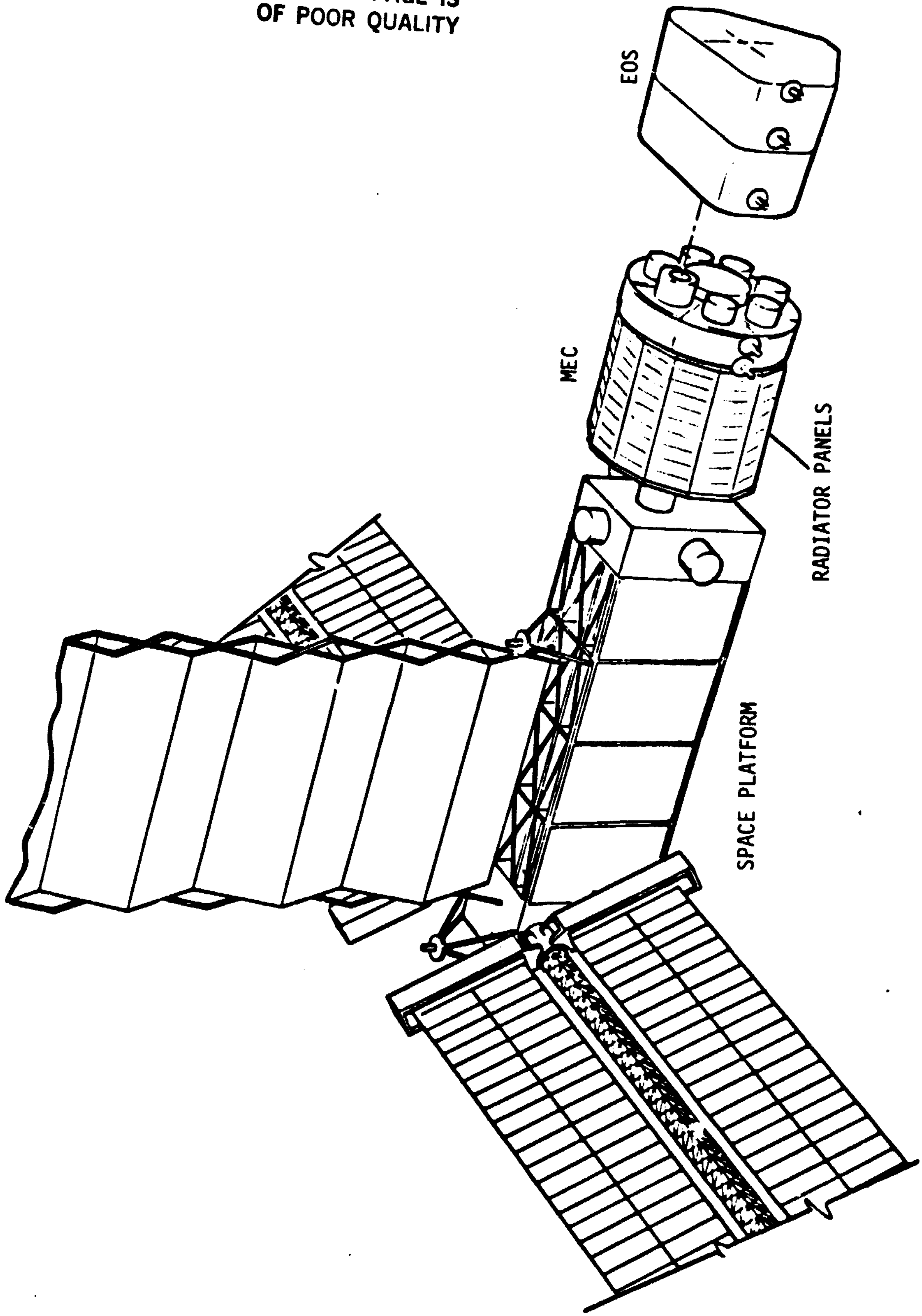

Figure 5-17. Hull-Mounted Auxiliary Radiator Concept

5. Provide load transfer via sill and keel support trunnions within MEC safe structural design limits and Orbiter interface constraints consistent with worst-case launch/ascent and descent/landing loads.
6. Avoid natural frequencies that would be coincident with Orbiter frequencies to minimize dynamic interaction problems.
7. Keep MEC internal stresses limited to acceptable levels with appropriate safety factors.
8. Be compatible with RMS handling during removal and restowage from/into Orbiter bay, mating (berthing) and unmating to/from Space Platform.
9. In all-up MEC, permit RMS and/or crew access to attached MPS payloads for servicing or replacement via appropriately placed, access doors or removable covers.
10. Provide berthing adapters for SP and EOS attachment, consistent with SP and SP companion payload clearance restrictions. The adapters will be standard hardware items to be defined in SP design.
11. Provide one (or more) RMS end effector grapple fixtures appropriately placed in fixed positions or manually attached/removable.
12. Provide crew access supports such as handrails and foot rest attach points.
13. If necessary, include provisions for carrying deployable or body mounted radiator panels.
14. If necessary provide a deployable/retractable exhaust pipe to prevent waste products from impinging on or interfering with sensitive SP or SP user equipment.

Most of these requirements were covered previously in configuration design (Section 4). Those that warrant further discussion will be addressed in this section, with emphasis on load transfer and frequency characteristics. With the Advanced MEA spoked disc design (appropriately modified) adopted as the preferred initial MEC support structure, some of the results obtained in the NASA/MSFC Advanced MEA Design Study (Reference 9) are directly applicable and provide a basis for discussion of MEC structural load and frequency characteristics, see Section 6.3.4 and 6.3.5.

Figure 5-18 lists assumed structural and equipment weights of the initial MEC, based in part on the Advanced MEA Study, and schematically shows respective locations in the center and the seven peripheral compartments of the spoked disc. Note the increase by about 2400 lb in the initial MEC weight which is primarily due to the addition of SES as payload.

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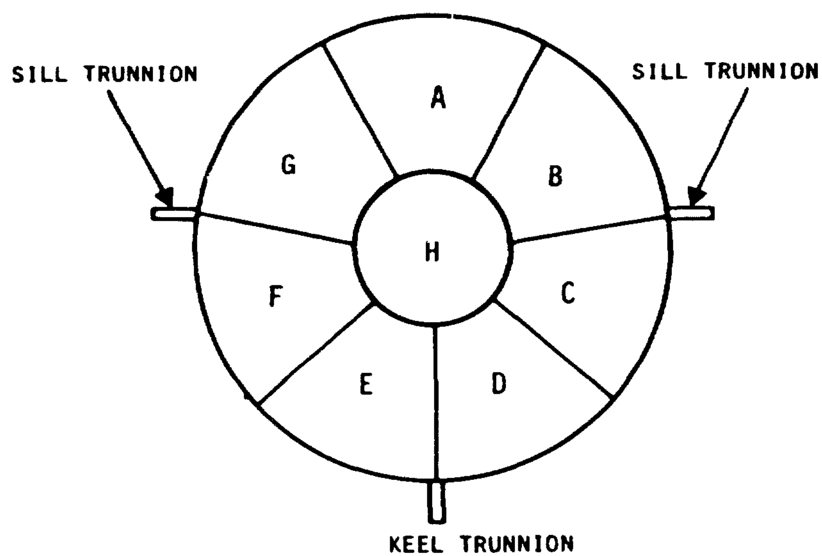

LOCATION	DESCRIPTION	ESTIMATED WEIGHT (LBS)
-	STRUCTURE (PLUS WIRING AND TUBING)	1170
H	BERTHING ADAPTER TO SP	80
A	BERTHING ADAPTER TO EOS	80
A	CDMS, THERMAL CONTROL AND POWER DISTRIBUTION SUBSYSTEM	800
B	MEA 1	440
C	MEA 2	440
D	MEA 3	440
E	MEA 4	440
F	MEA 5	440
G	MEA 6	440
H	SES	2200
TOTAL (EXCL. CONTINGENCY)		6970

FOR COMPARISON, ADVANCED MEA (SPOKED DISC) WEIGHT=4595 LBS, INCLUDING PAYLOADS. REFERENCE: NASA, "ADVANCED MEA STUDY," MARCH, 1981

Figure 5-18. Summary of Assumed Weights and Locations (Initial MEC)

5.6.2 Design Concept

The modified MEA spoked disc structure of 170-inch outer diameter and 30-inch width includes a seven-sided central compartment, sized to accommodate the 60-inch diameter SES payload, and seven truncated, pie-shaped peripheral compartments that accommodate six MEA facilities (Compartments B through G in Figure 5-18) and the MEC support subsystems (Compartment A).

The bulkhead covering the disc on one side is designed to carry the end-mounted MEA canisters as cantilevered loads. Subsystem equipment in Compartment A is mounted to the bulkhead or the compartment walls. The bulkhead also support most of the MEC electrical cabling and coolant ducts (see Figure 5-19). The SP berthing adapter is attached to the center of this bulkhead where direct load transfer to the hub structure is provided by the adapter mounting bolts.

The bulkhead on the opposite (aft facing) side has openings that permit axially mounted payloads to protrude, if necessary. These openings provide access for payload ground installation or servicing. They also make payloads accessible in all-up MEC missions for on-orbit servicing or replacement.

As an alternative to axial payload access radial access also was considered (Figure 5-20). In either case the access doors greatly reduce the spoked disc structural stiffness, however, the effect is less severe with openings located in the bulkhead than in the hull. For this reason and because of other functional advantages discussed in Section 4.3.1 the axial payload mounting/access option was selected.

The hull, ribs, hub and bulkheads are of aluminum construction, with stiffeners mounted inside along all edges. Access door covers are designed to be firmly bolted down before launch, to restore some of the stiffness lost due to the aft bulkhead openings. Additional stiffening may be necessary to increase MEC natural frequency to the point where resonance and interaction with Orbiter frequencies is avoided (see below).

5.6.3 MEC Disc Load Transfer

Two alternate MEC spoked disc support methods in the Orbiter bay were considered (see Figure 5-21) which use either 3, 4, or 5 standard payload mounting trunnions:

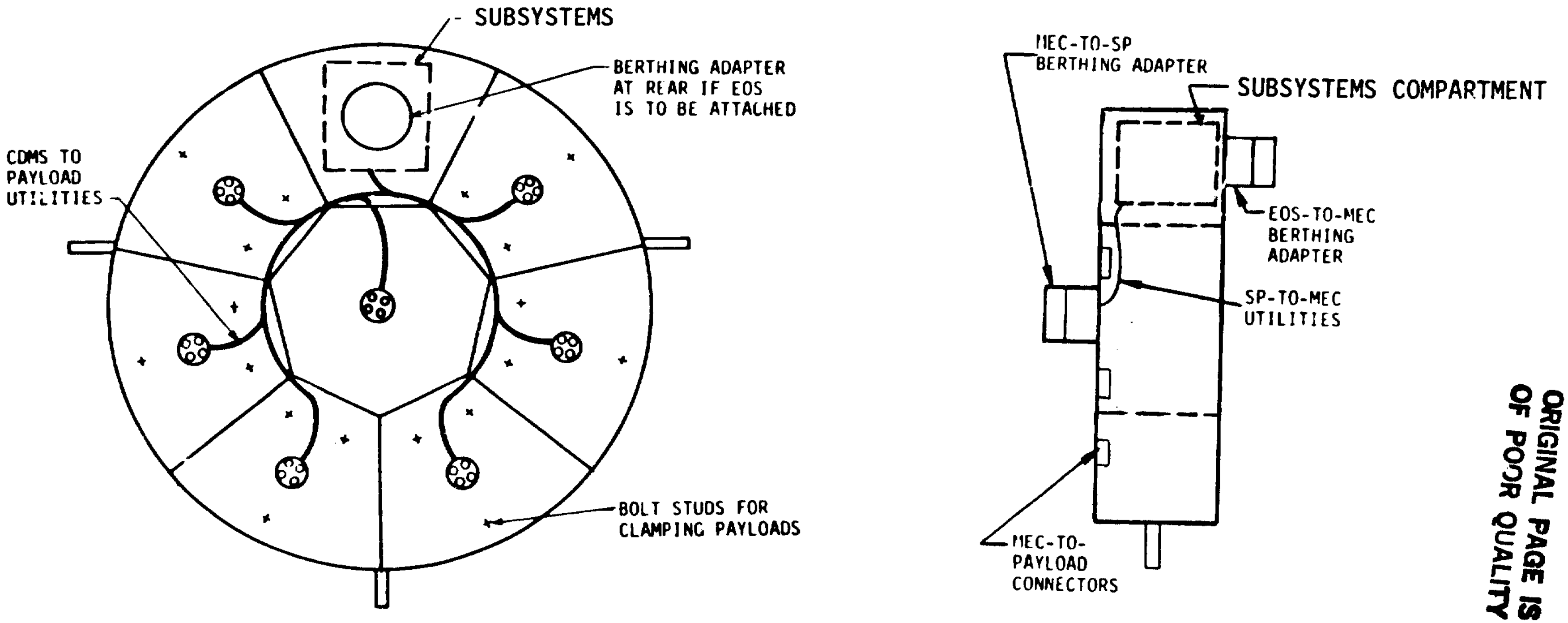

Figure 5-19. Routing of Electrical Wiring and Fluid Piping for MEC Utilities

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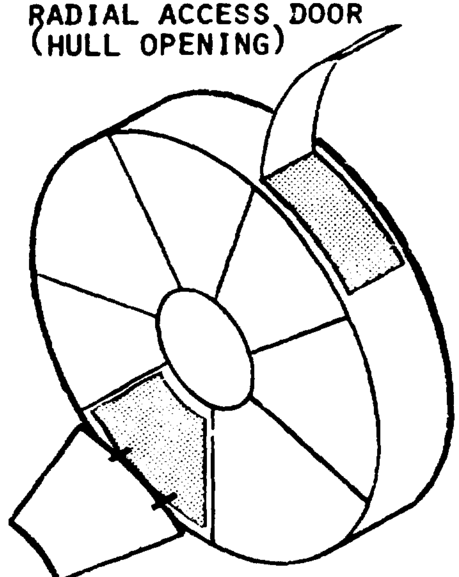

- REACTION FORCES ON ORBITER DO NOT DEPEND ON DOOR LOCATION
- MEC STRESSES ARE LOWER FOR ACCESS DOORS IN BULKHEAD
- NATURAL FREQUENCY IS HIGHER FOR ACCESS DOORS IN BULKHEAD. THUS, FOR STRUCURAL REASONS AXIAL ACCESS IS PREFERABLE FOR PRESENT MEC.* THIS CONCLUSION SHOULD BE RECONSIDERED FOR THE ALL-UP MEC.

*ALSO PREFERABLE FOR ACCOMMODATION OF LARGE, PROTRUDING PAYLOADS

Figure 5-20. Door Access Location Alternatives

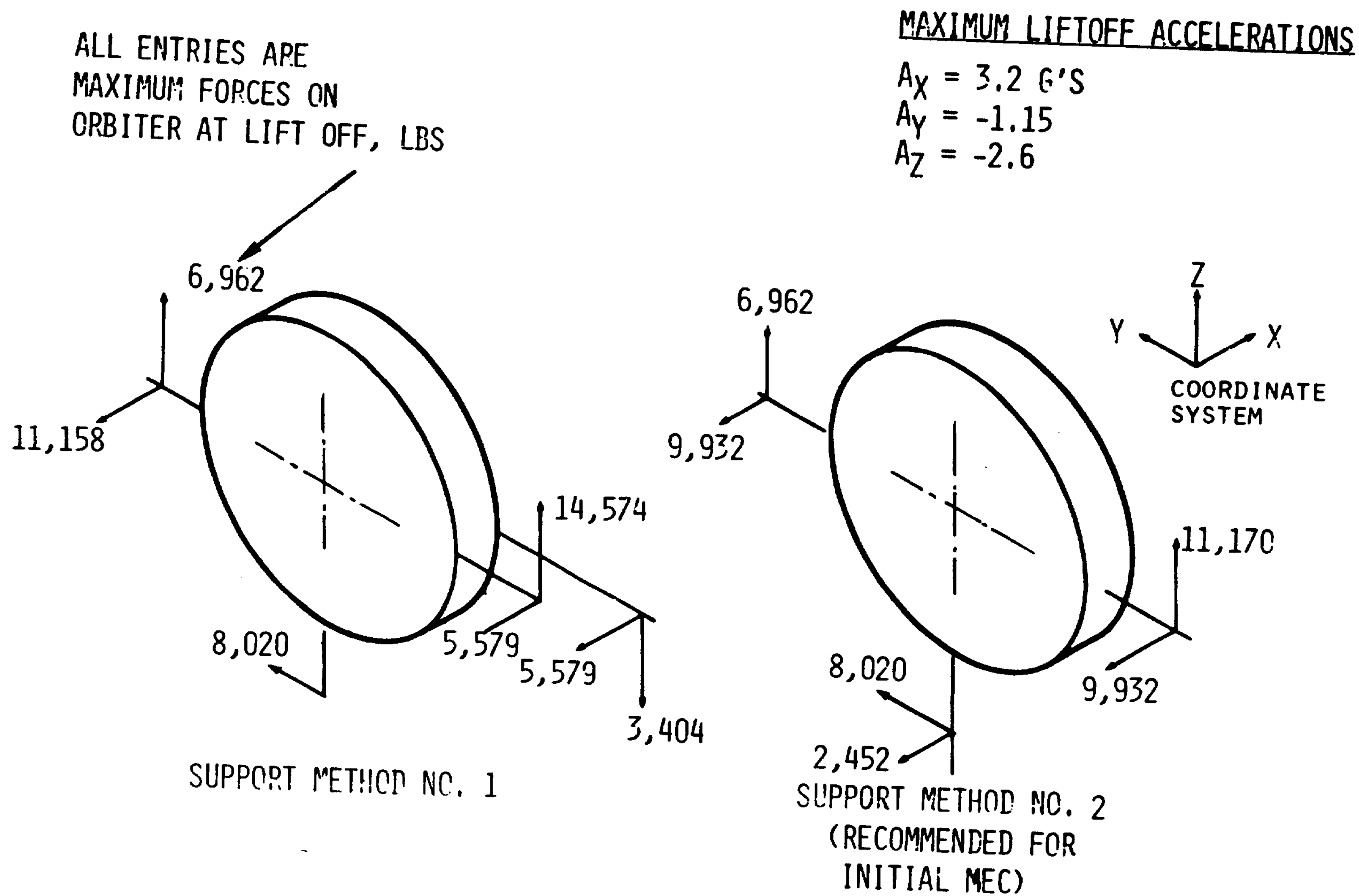

Figure 5-21. MEC Disc Load Transfer

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Method 1:

- Three (or four) sill trunnions with the keel trunnion carrying only lateral (Y) loads
- No special (active) keel support is required
- MEC can be mounted at any Orbiter location

Method 2:

- Two sill trunnions, with keel trunnion carrying lateral (Y) plus axial (X) loads
- Requires special keel support, not available at all Orbiter locations
- Requires monitoring of keel fitting alignment during restowage on oribt
- Requires added hoist attachment for ground handling
- Advantages:

  - Higher natural frequency (see next section)
  - Lower MEC stresses
  - Lower Orbiter reaction forces

Both methods comply with Orbiter/payload interface specifications (Reference 10) although the second method generally is limited as to maximum longitudinal (x-axis) loads that can be reacted through the keel trunnions.

Reaction forces were determined by static analysis using assumed MEC weights and maximum liftoff and landing accelerations (see Table 5-5).

Table 5-5. Maximum Accelerations (g's)

	A_x	A_y	A_z	A_x	A_y	A_z
Liftoff	3.3	-1.157	-2.34	3.2	1.15	-2.6
Landing	-2.0	-1.315	4.987	-2.0	-1.3	4.98

The reaction forces indicated in Figure 5-21 correspond to liftoff conditions. Under landing conditions maximum sill trunnion loads are approximately twice as large as during liftoff.

Note that method 1 produces considerably larger vertical trunnion loads (on the sill with two mounts) than method 2, and conseqeuntly, large bending moments on that sill. For this reason and the more favorable

natural frequency response obtained in method 2 (see below) the latter method is adopted for MEC.

The critical load is the longitudinal keel reaction force. Figure 5-22 is a plot of Orbiter keel load capability in x-direction versus x-station location in the Orbiter bay. The 2,452 lb keel force reaction shown in Figure 5-21 to occur with support method 2 is indicated as a dashed horizontal line. (The corresponding smaller MEA keel reaction force (1,760 lb) obtained in the MSFC study is also shown for comparison). It is seen that in most of the cargo bay locations the Orbiter keel load limits are two to three times greater than the maximum load exerted by MEC except in the extreme forward part of the cargo bay (up to station 680) where the load capability would be insufficient.

A similar analysis on MEA performed at NASA/MSFC also shows acceptable reaction loads for most payload positions.

5.6.4 MEC Natural Frequency and Internal Stresses

Sufficient stiffness of the MEC spoked disc structure is required to keep its fundamental natural frequency different from Orbiter frequencies thereby minimizing dynamic interaction. As sketched in Figure 5-23 there exist several "windows" in the Orbiter frequency spectrum where interactions with MEC low natural frequencies might be avoided, but because of load variations and other uncertainties it will be safer to raise the MEC frequencies into the desired region above 16 Hz.

Previous NASA/MSFC analysis of the spoked disc MEA, using NASTRAN, showed a fundamental frequency of 19 Hz if compartment doors carry loads but only 3 Hz if they do not. MSFC's recommendation is to increase stiffness around the panel doors to carry more load. Alternately, riveted or tightly bolted door panels could be used for payloads or compartments that do not require access in space.

Simplified MEC structural analysis indicated that support method no. 2 (with keel axial support) will result in natural frequencies similar to MEA. Support method no. 1 will result in lower frequencies. The sketches of bending mode shapes in Figure 5-23 (bottom) for the two support methods illustrate this difference. Method 2 was selected as the preferred MEC disc trunnion support design.

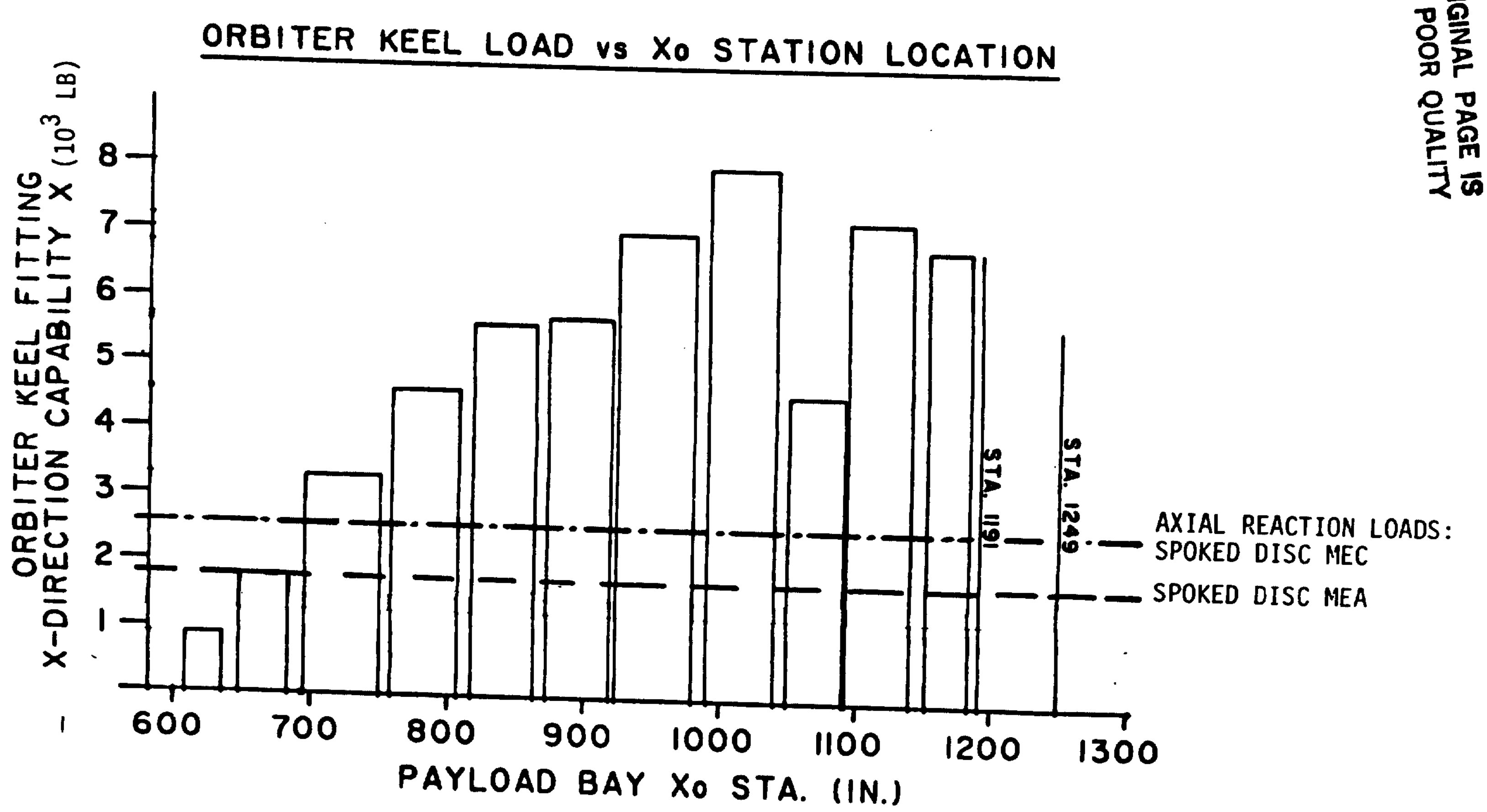


Figure 5-22. Orbiter Keel Fitting X-Axis Load Capability and Spoked Disc Reaction Loads (Ref.: MSFC Study of Advance MEA, March 1981)

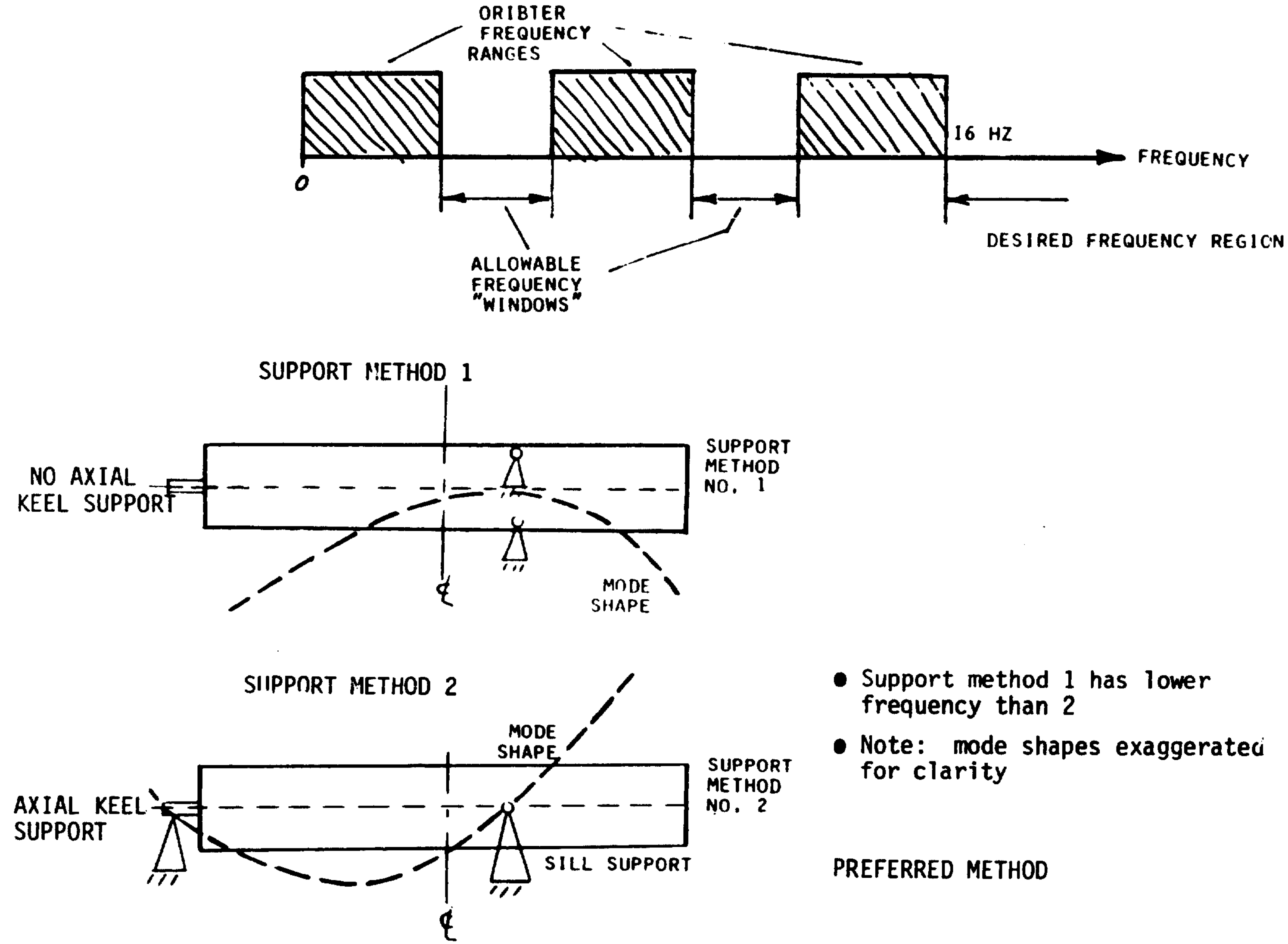


Figure 5-23. MEC Natural Frequencies

The MSFC analysis of the MEA spoked disc shows acceptable stress levels. The MEC design using support method 2 is similar to MEA but will have higher stresses due to larger maximum bending moments. These moments can be reduced, however, optimizing the weight distribution for each set of payloads, keeping the center of mass close to the sill elevation. This means that the heaviest payload units should be mounted in compartments B and G or C and F, the lightest in compartments D and E (Figure 5-18). The large weight (800 lb) carried in the subsystem compartment (A) tends to affect this mass balance favorably. Optimization to minimize stresses also tends to increase the natural frequency.

In an effort to raise the MEC natural frequency to the desired range above 16 Hz several approaches were investigated:

a) Use of rivets or closely-spaced bolt patterns for payload access doors as previously mentioned.

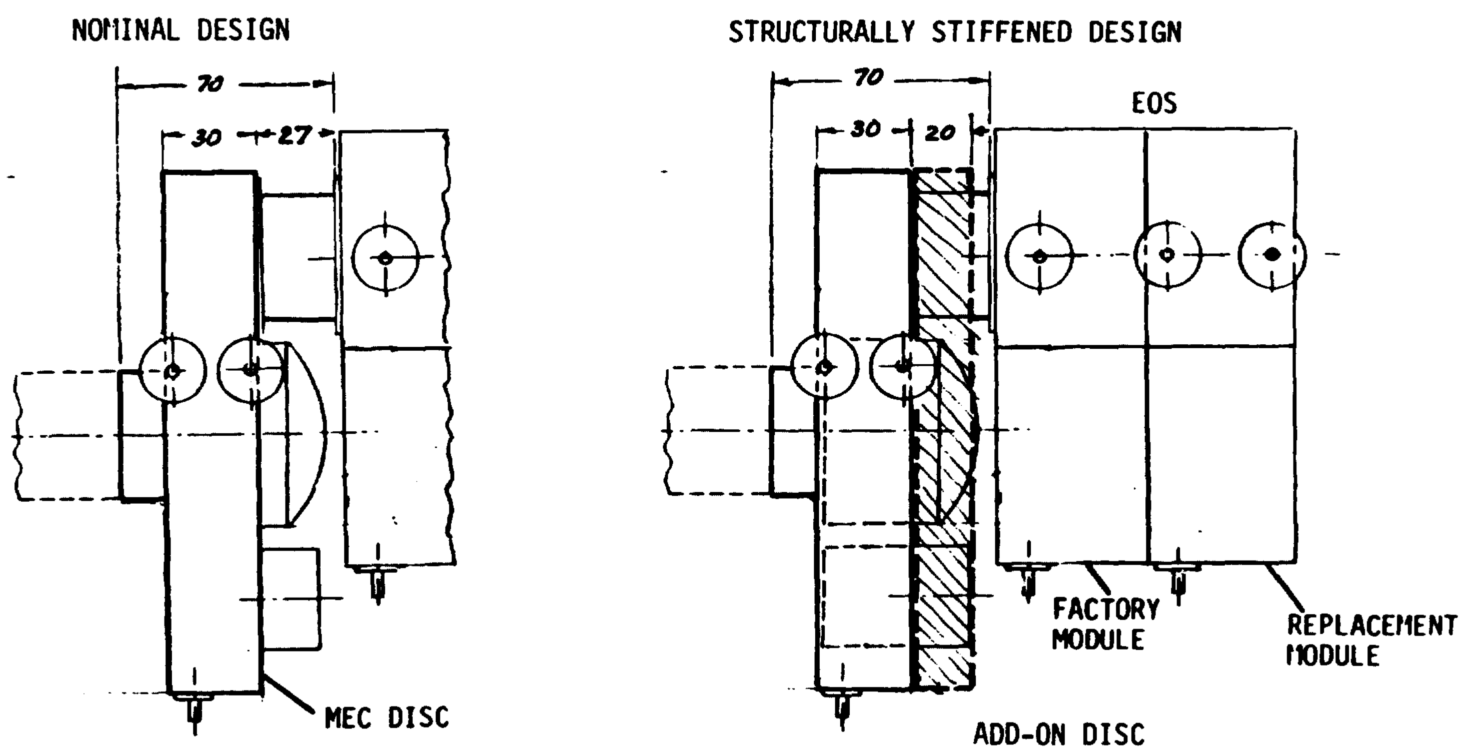
b) Additional cross-bracing. Although the present design adapted from the MSFC's MEC design contains braces at all edges, cross-bracing could be added. The object is to ensure that all loads are carried in panel shear or tension/compression, not in bending of panels or braces.

c) Additional door bracing to minimize the effects of access doors. Specifically, if enough bracing were added to assure that loads are carried in tension/compression only, and bending of the braces were eliminated, the 3 Hz frequency obtained with no doors could be raised to about 12 Hz.

d) If in addition, the disc width were doubled from 30 to 60 inches, the natural frequency could be raised to approximately 38 Hz.

Note that these results are obtained from approximate first-order hand calculations and should be refined by conducting a more detailed finite element analysis.

Item d) above promises to produce the desired frequency increase without major design complication, albeit at the cost of a significant weight increase. The recommended approach (e.g., if an existing MEA structure were to be modified for MEC use) is to add an extension disc of 20-inch thickness raising the frequency from 12 to about 20 Hz. As shown in Figure 5-24 this would not mean additional chargeable MEC cargo bay length, since only the space otherwise allocated to the EOS adapter is taken up by the add-on disc.



- NATURAL FREQUENCY RAISED TO 20 Hz
- SIMPLIFIED PAYLOAD INSULATION
- NO INCREASE IN LENGTH DEPENDENT LAUNCH COST

Figure 5-24. MEC Structural Stiffening by Add-On Disc

The added structural weight is estimated to be about 130 lb (for hull, rib and hub structure extension).

5.6.5 Transition To All-Up MEC

Figure 5-25 shows the structural support concept to be used in the transition to all-up MEC where a growth module carrying four large payloads is added to the MEC disc structure (core module). The following are principal features of the structural design:

- Payloads are supported at ends (requires laterally stiff payloads)
- Payloads are connected directly to the end rails, which are supported at bulkhead stiffners
- Bulkheads carry all y and z loads in shear directly to the supports
- Stiffeners strengthen bulkheads against bending due to x loads
- Four point (redundant) sill mount with two keel supports (lateral load only) gives favorable natural frequency and stress characteristics

5.7 SUBSYSTEM RELATIONSHIP OF INITIAL MEC TO ADVANCED MEA

Table 5-6 indicates the areas of the initial MEC subsystem design that have commonality with advanced MEA subsystems. It is apparent that, except for the nearly identical support structure, there are only few MEA subsystem components directly applicable to MEC. However, the subsystem design concepts show simularities except for sizing and a degree of flexibility reflecting the differences in mission profiles, operating modes, payload complexity and diversity.

With the MEA design not as yet firmly established at this time, an effort to develop subsystems with an architecture and characteristics compatible with subsequent evolution to MEC requirements might be appropriate. However, considerable further study would be necessary to determine whether this approach is practical and also economically advantageous.

5.8 BREADBOARD/BRASSBOARD PLANNING

Breadboard and brassboard design and planning for the initial MEC should consider the MEC subsystems of: structure/mechanisms, power distribution, thermal control, command/data management, and the candidate MEC/MPS payloads. The payloads considered should scope the range of potential MPS discipline applications including Isothermal, Gradient Freeze,

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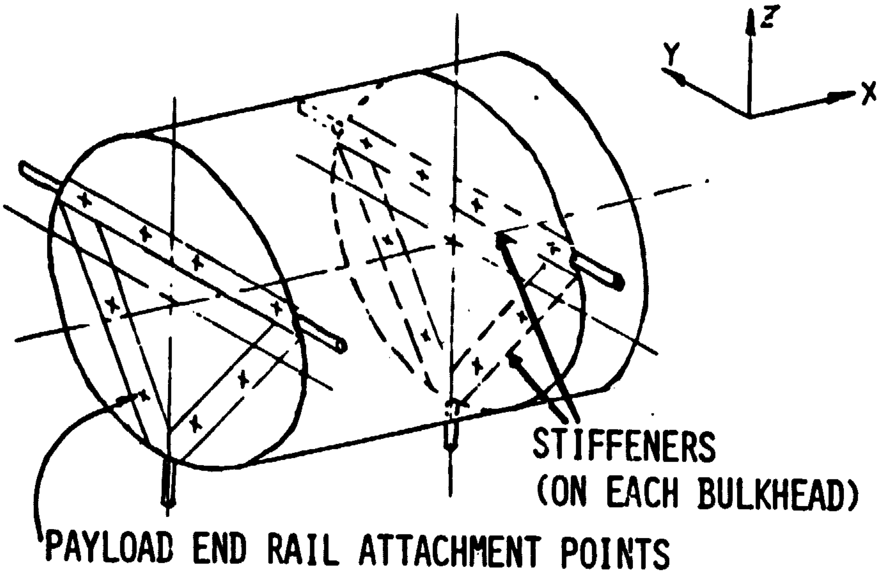

Figure 5-25. Transition to All-Up MEC

Table 5-6. Subsystem Relationship of Initial MEC To Advanced MEA

STRUCTURE:	• MEA spoked disc adapted to initial MEC with minor modifications. Axial payload access. • Center compartment enlarged to accommodate 60 in. diam. SES • SP and EOS berthing adapters added to disc structure.
ELECTRIC POWER:	• Differences in power level and voltage levels (3 to 4 kW, 30 VDC for MEA; 12.5 kW, 30 V and 120 VDC for MEC) require redesign of EPDS, with little or no commonality.
THERMAL CONTROL:	• Both MEA and MEC use pumped coolant loops with parallel rather than serial flow through payloads. • MEC requires larger heat transfer capacity, larger flow rates (EOS accommodation), hence redesigned fluid loop • Selection of Freon 21 as coolant permits commonality of some components
COMMAND AND DATA MANAGEMENT:	• Some subsystem architecture commonality between advanced MEA and MEC (serial data bus approach). • Adaptation to MEC of DACS, used on MEA, or some of its components. • Major operating idfferences (MEA stores all data, MEC periodically stores and dumps data via SP downlink, requires full autonomy, longer mission duration) preclude design commonality.

Directional Solidification, Containerless Processing (acoustic, electromagnetic, electrostatic), Bioseparation and Solution/Vapor Crystal Growth. In the setting up of a first step MEC breadboard plan for future implementation, critical elements of at least three of the above payload disciplines, in addition to the critical MEC subsystems elements, should be considered in the make-up of an integrated breadboard. Decision as to the extent of MEC subsystems functions and the specific payloads to be pursued in breadboard/brassboard planning should be made in time to incorporate the plan into downstream, Phase B, MEC design activity.

The MEC breadboard/brassboard concepts should be established per the following groundrules:

1) Low cost initial utilization with extended growth.
2) Conservative growth of total simulation capability.
3) Flexible adaptation to a variety of MEC subsystems and MEC payload sizes, groupings, and system performance levels.
4) Maximum hardware integration simplicity.
5) Optimum division between MEC subsystems development, MEC payload development, and MEC interface definition.

The following definitions are offered:

Breadboards are non-flight commercial or manufactured hardware components assembled for the purpose of demonstrating performance of an operation or function. Breadboards are usually a loose assembly of components/hardware that does not resemble flight hardware in form or fit, but does match it in function.

Brassboards are integrated and operational hardware components (non-flight) of full scale fit, form, and configuration for the purpose of demonstrating solutions to interface problems. They are usually assembled to demonstrate a flight operational configuration, but do not have to meet flight specifications or performance criteria.

5.8.1 Why Breadboards

Key objectives of breadboarding electronic circuits and systems include the following:

1) To verify the ability of circuits, as designed to perform their desired tasks.

2) To experimentally characterize component parameters that are still unspecified.

3) To validate a design experimentally when analytical validation is impractical or impossible.

4) To facilitate comparison of competitive approaches for the purpose of selecting an optimum approach.

5) To evaluate a portion of an existing piece of equipment for a new application.

6) To provide test circuits, in lieu of final hardware, to allow test of partial or complete systems and to study the integration of various portions of systems.

7) To provide a functioning system which will allow one phase of a program to proceed independent of the final hardware and other phases of the program.

Objective 1 is the most common. An example of objective 2 is the selection of an accurate voltage reference diode. Diodes have some maximum voltage drift specified over temperature at specified current. It is known that at some current (generally slightly different than specified) each diode will have a near zero temperature coefficient. A breadboard could be constructed to determine the ØTC current for each diode. An example illustrating objectives 6 and 7 is the construction of a microprocessor-based system using commercial boards so software development can continue independent of other portions of the project.

5.8.2 Approach to Breadboard/Brassboard Planning Considerations and Suggested Approach

Breadboard design and planning requires special treatment. One must first identify the MEC key operational features that are dependent upon technology, then do design and planning work for critical elements. Planning considerations include:

1. What to breadboard and why do it?
2. Design of the breadboards.
3. How to conduct breadboard operations (testing) to get proof-of-concept data?
4. When (Phase B, or C/D) is best to carry out each element of the breadboard plan?

These critical parts from MEC subsystems are recommended for breadboarding:

- Adaptive intelligence part of the CDMS operation in concert with simulated MEC payloads.
- Networking of electrical power distribution/control
- Real-time payload control using a remote operator to simulate a MEC flight-ground based operator situation
- Payload sample insertion/retrieval
- MEC-to-MPS payloads thermal interfaces

The approach to a MEC project breadboard plan is depicted by the activity breakdown shown in Figure 5-26 and the decision flow of Figure 5-27.

5.8.3 Breadboard Contents

A breadboard may contain circuitry functionally the same as the anticipated final hardware but with open construction. It may have parts different from the final hardware and may have generically equivalent parts. It will ordinarily withstand flight temperatures but not humidity, vibration or EMI. It can be simpler than final hardware, e.g., one may only breadboard a few channels of a many-channel multiplexer, or it can be more complex. An AD converter breadboard may contain all the clock signal and timing logic while the final circuit may receive these signals from another source. A breadboard may be of totally different circuitry but function the same as final hardware. E.g., if the breadboard needs a microcomputer, a commercial product may be used (to save time and money).

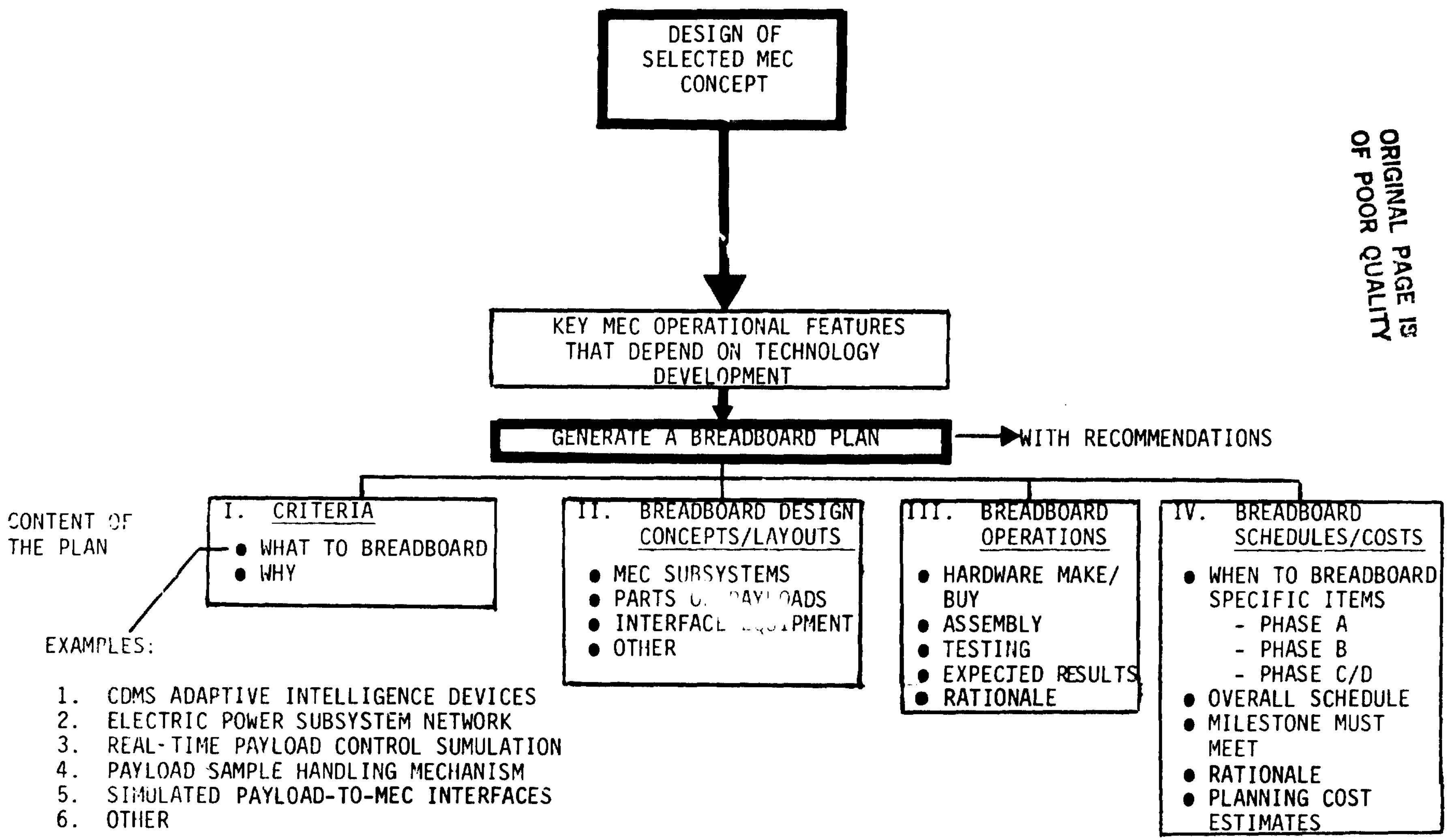

Figure 5-26. Approach to Breadboard Plan

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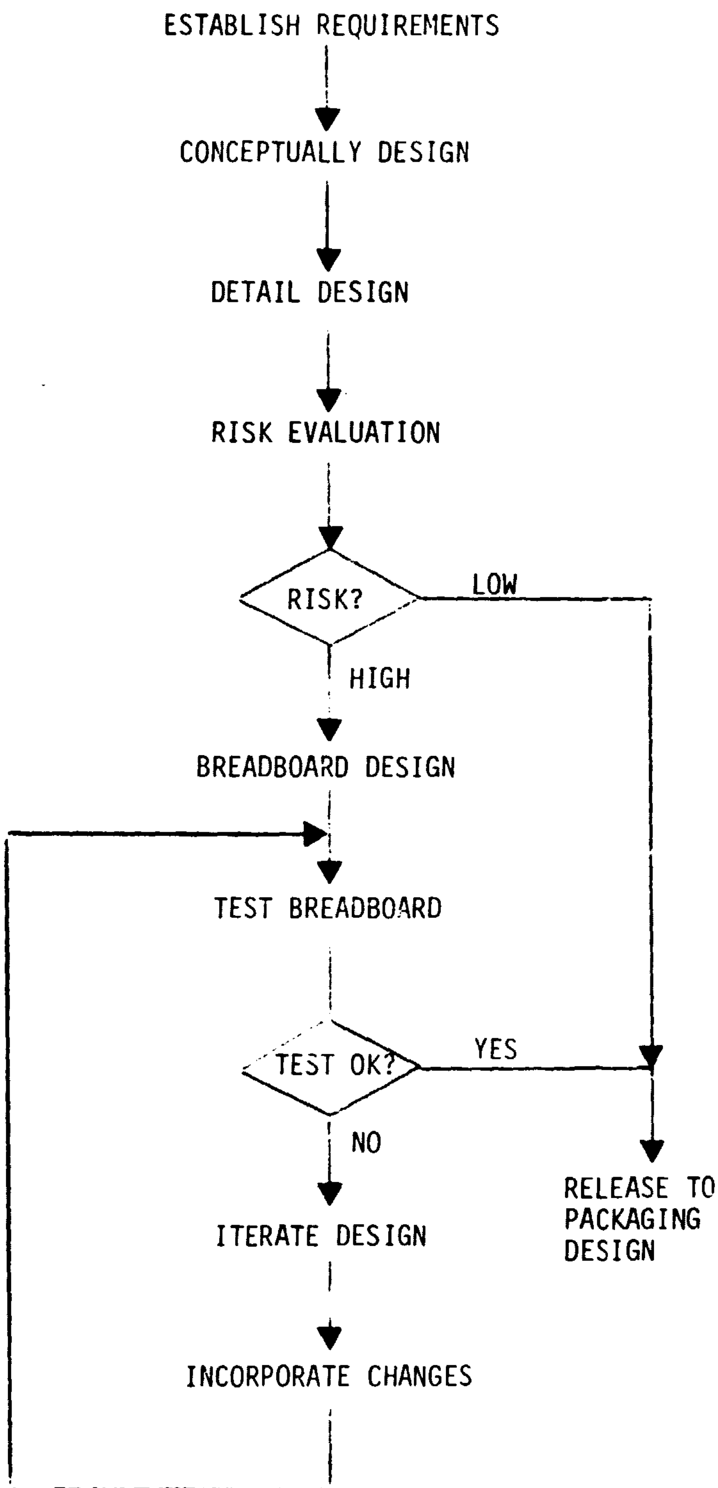

Figure 5-27. Breadboard Plan Decision Flow

6.0 SYSTEM AND MISSION OPERATIONS

Material presented in this section draws on mission analysis and trade study data previously reported in Reference 6, updated to reflect the revised MEC mission profile and the evolution from an initial to an all-up MEC system concept. These revisions affect, in particular, the discussion of on-orbit servicing options, Shuttle and Space Platform utilization and mission cost issues (subsections 6.5 to 6.7).

6.1 MISSION CHARACTERISTICS

MEC will be carried to orbit, attached to the Space Platform and deployed into the free flying mission phase by the Shuttle Orbiter. At the end of the mission the MEC will be retrieved by the Orbiter and returned to the ground.

With Space Platform revisits by the Orbiter projected to occur once every six months, the initial MEC will stay in orbit for just this length of time, to be retrieved on the first SP revisit.

The all-up MEC may remain in orbit for longer missions that extend over more than one revisit time interval, i.e., 12 months, 18 months or longer. During revisits, in extended MEC missions, the Orbiter will perform essential services such as payload exchange, processed sample exchange, or possibly replacement of defective support systems. Typically with mission durations and turn-around times between missions lasting 6 months each one MEC relaunch may be performed per year.

The projected initial MEC, flight date will be 1987 or later keyed to the IOC of the Space Platform.

Dates for MEC launch, servicing and retrieval must be planned to make use of Shuttle ride sharing opportunities since MEC or the equipment used for MEC servicing will utilize only part of the Shuttle cargo capacity.

MEC related launch dates and daily launch windows are constrained by the Space Platform rendezvous requirements. Depending on SP orbit inclination there will be one or two daily launch windows.

MEC will not restrict SP orbital characteristics in terms of altitude or inclination except for requiring operating altitudes above the level where the maximum atmospheric drag deceleration would exceed the limit of 10^{-5}g,

i.e., typically 160 n.m. (Note: SP will avoid altitudes in this region, in any case, because of large drag makeup maneuver requirements).

SP orbital characteristics preferred by MEC are those that provide (a) maximum average power and (b) convenient access by the Shuttle for deployment, servicing and retrieval. In order to get the best Shuttle cargo weight performance and to minimize transportation cost for MEC launch, retrieval and servicing, low inclination SP orbits will be preferred.

6.2 REFERENCE MEC MISSION PROFILE

Principal MEC mission phases include

- Launch by the Shuttle Orbiter
- Rendezvous with the SP
- MEC attachment to the SP
- Orbital deployment of SP/MEC as free-flyer
- Materials processing operations on orbit
- Retrieval by the Orbiter and return to ground

In the all-up MEC the mission profile may include on-orbit servicing.

Composition of the MEC payload, required mission duration and projected Shuttle SP revisit dates will dictate the time of servicing events. Mission profiles with or without servicing are shown schematically in Figure 6-1. Mission phases and sequences are illustrated in Figure 6-2.

The sequence of on-orbit operations required to deploy the MEC during a Shuttle/Space Platform rendezvous mission is illustrated in Figure 6-3. After rendezvous, retrieval and berthing of the Space Platform on a berthing port provided for this purpose in the Orbiter cargo bay, the MEC will be removed from its stowed position and attached to one of the SP payload ports. When attached, the SP/MEC will be checked out as a functioning system before release by the Orbiter to start free-flying operations.

The Shuttle Remote Manipulator (RMS) arm will be the primary support hardware used to capture and berth the SP and to accomplish MEC unstowing, transfer and SP berthing port attachment.

Assistance by crew member extra-vehicular activity shall be required as a backup in supporting the remotely controlled RMS operations. Stringent safety requirements shall be observed to avoid potential hazards to the Orbiter and crew that are inherent in all phases of this study.

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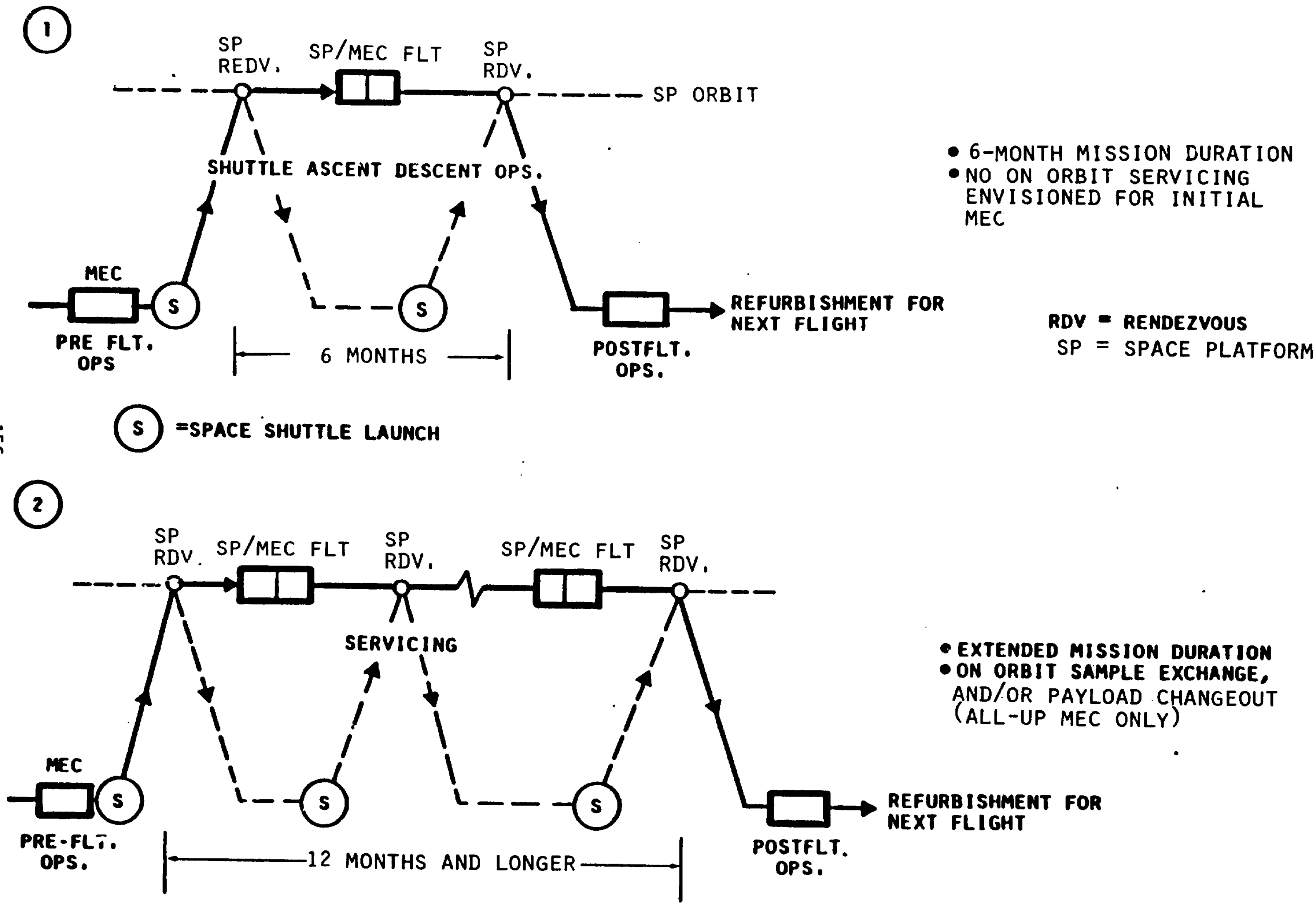

Figure 6-1. MEC Mission Profiles Without and With On-Orbit Servicing

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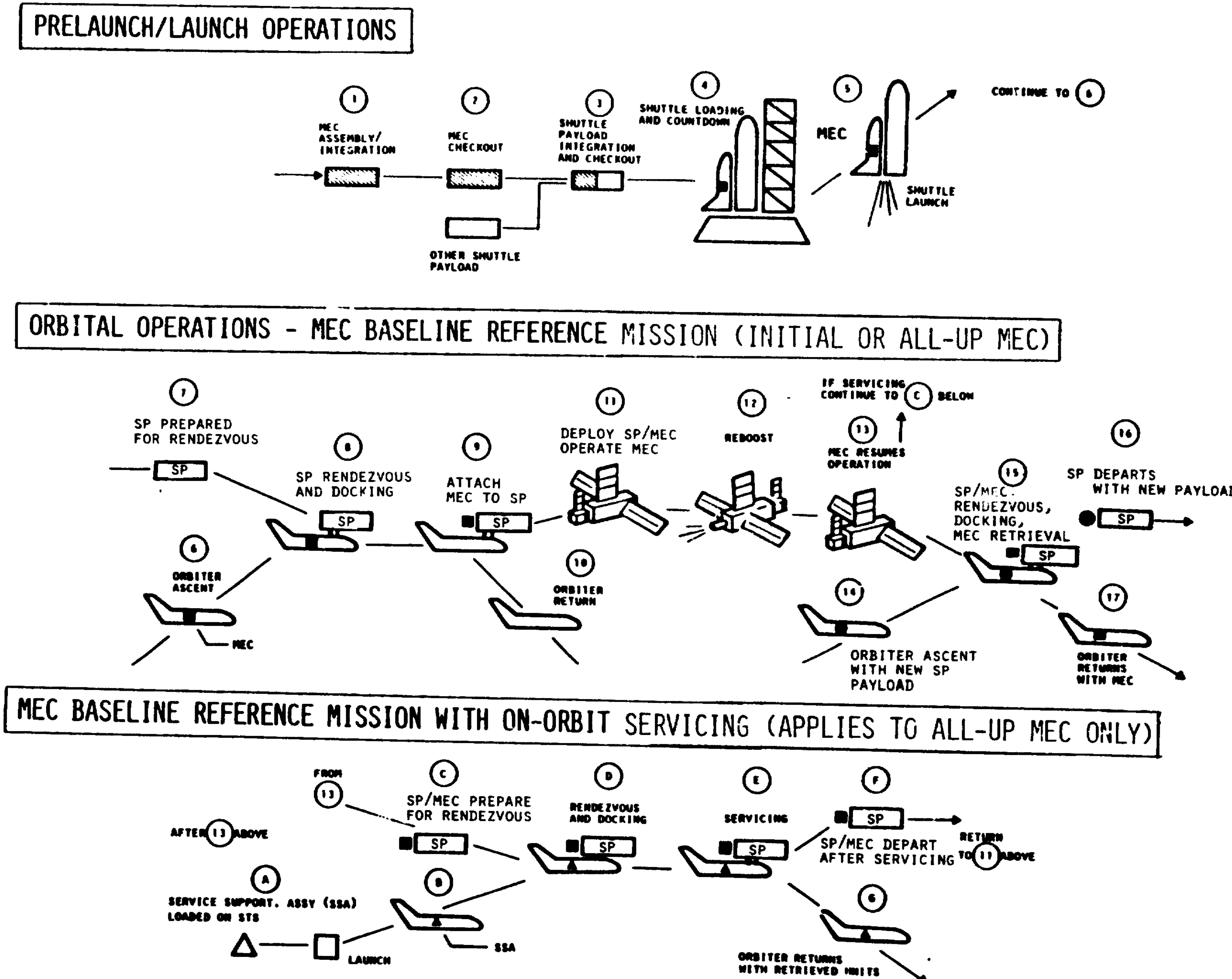

Figure 6-2. MEC Mission Sequence of Events

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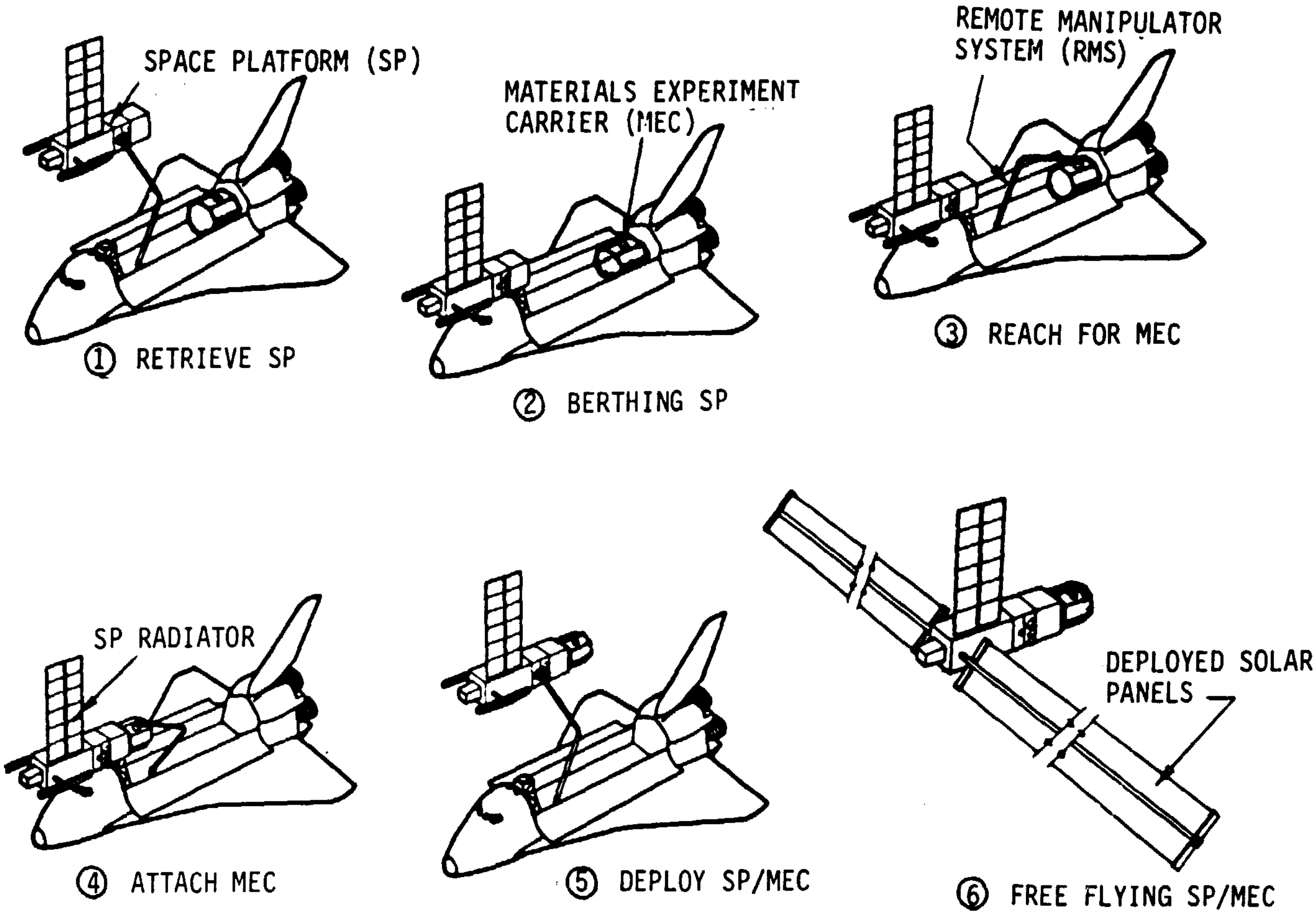


Figure 6-3. MEC Deployment Sequence

Sequences similar to those shown in Figure 6-3 will be employed in MEC retrieval from orbit and on-orbit servicing activities.

As an alternative, MEC deployment, retrieval and servicing sequences may be supported by the Teleoperator Maneuvering System (TMS). Thus, the TMS may be utilized to aid in achieving Orbiter rendezvous with the SP and in redeployment of the SP; or to carry MEC to or from the SP if direct SP rendezvous/docking with the Orbiter is to be avoided; or to carry MEC payload units from the Orbiter to the SP/MEC and back to the Orbiter in remote servicing operations.

Major mission events from pre-launch through launch, orbital operations and retrieval are summarized in Table 6-1 which also gives preliminary event time estimates.

Table 6-1. Summary Mission Event Schedule (Typical Mission Profile)

EVENT/OPERATION	EVENT TIME*	EVENT DURATION	
1. Start MEC prelaunch integration at KSC	L - 2 mo.	2 mo.	
2. MEC Orbiter integration	L - 3 wk.	3 wk.	
3. Launch	L		
4. Start STS orbital operations	L + 0.5 hr.		
5. Complete SP rendezvous and berthing	L + 6 hr.	6 hr.	
6. Complete MEC/SP attachment	L + 12 hr.	6 hr.	
7. MEC/SP interface verification and checkout	L + 18 hr.	6 hr	
8. SP/MEC separation from Orbiter	L + 20 hr.		
9. Start SP/MEC orbital operations	L + 22 hr. (→M)	30 to 180 d.	
10. SP reboost operations	M + 30 d every 30 d.	1 hr.	
11. Complete first MPS phase (pre-servicing)	M + 180 d.		
12. SP/MEC retrieved by Orbiter for servicing	M + 180.5 d (→S)	6 hr.	
13. MEC on-orbit servicing	S + 6 hr. (or longer)	6 hr. (or longer)	
14. Post-servicing checkout	S + 10 hr.	2 hr.	Applies To All-Up MEC Only
15. SP/MEC redeployed	S + 12 hr.	2 hr.	
16. Start second MPS phase (post-servicing)	S + 14 hr.	30 to 180 d. (or longer)	
17. Launch Orbiter; retrieve MEC	L + 180 d (or longer)	6 hr.	
18. Return MEC to ground	S + 181 d (or longer)		

*Time of completion except were stated otherwise

6.3 MEC OPERATING MODES

MEC will be designed to function in a number of standard operating modes, as required by the mission sequence, including the following:

(1) Launch and retrieval mode, in Orbiter bay

(2) SP-attached sortie mode

(3) SP-attached free-flying modes

- MEC payload operation mode
- MEC standby (dormant mode)

(4) On-orbit servicing mode (in all-up MEC missions only)

(5) Transfer mode

(6) Checkout/verification mode

6.3.1 Launch and Retrieval Mode

Launch and retrieval will be performed with MEC stowed in the Orbiter cargo bay. MEC shall use auxiliary power supplied by the Orbiter to maintain thermal control of critical subsystem/components and minimum command/data acquisition capabilities.

6.3.2 SP-Attached, Sortie Mode

In this mode, MEC will be attached to a SP payload port, with the SP berthed on the Orbiter: (1) prior to orbital deployment in the free-flying mode, (2) prior to restowage in the Orbiter bay for return to the ground, (3) during servicing and (4) during checkout activities. Payload systems generally will be dormant except during checkout and verification activities.

6.3.3 SP-Attached, Free-Flying Mode

While attached to the SP, during most of the free-flying mission phase, the MEC will be in the normal, payload operation mode providing functional support to materials processing activities by the payloads. Repeated steps of sample handling, processing and storage will be controlled by automatic sequences.

Interruptions will occur during programmed events such as reboost maneuvers, and during Shuttle revisits for servicing and/or access to the MEC, the SP or other SP payload elements.

Materials processing normally will be performed by automatic sequencing autonomously within each payload, under executive control by the MEC central computer and subject to monitoring and override control or reprogramming from POCC via TDRSS. Evolution of fully autonomous operation capabilities will reduce reliance on around-the-clock ground monitoring and support, and save cost.

6.3.4 On-Orbit Servicing Mode (All-Up MEC)

In the servicing mode, involving access to MEC for changeout of entire payloads or sample magazines, all live circuits including housekeeping circuits must be shut off as a safety measure. Shut-off will be initiated prior to direct servicing, in the sortie mode, or remote servicing by the Teleoperator, in the free-flying mode.

MEC will provide the necessary thermal protection to all subsystems and payload elements during the dormancy periods involved in servicing.

6.3.5 Transfer Mode

This mode will be used during transfer by the RMS between the stowed position in the cargo bay and attachment to the Space Platform, or during transfer service provided by the Teleoperator. In this mode the MEC remains dormant, with its thermal radiator (if carried on the mission) in the stowed configuration.

For transfer by the Teleoperator which may extend over an interval of several hours, an auxiliary battery on MEC will provide stay-alive housekeeping/heating power.

6.3.6 Checkout/Verification Mode

Checkout and verification will be required in the sortie mode, prior to SP/MEC deployment, or in the free-flying mode, after remote servicing by the TMS, and occasionally between normal processing sequences, as required. Subsystems and payloads will normally be placed in operating condition during checkout operations.

The checkout will be carried out primarily by automatic sequences. However, if necessary under anomalous conditions, the mode may also include monitoring and/or control by the Orbiter crew or ground facilities personnel.

6.3.7 Time Sharing of SP Resources

MEC materials processing operations will be affected by time sharing the SP power output and other resources with other SP payloads present.

Interface control and resource allocation will be executed automatically by payload management and control circuits and software in the SP Command and Data Management Subsystem, in accordance with priority allocations determined in advance by mission planning.

6.4 SYSTEM INTEGRATION AND CHECKOUT

6.4.1 MEC Development, Integration and Test Schedule

A top level project schedule was developed, primarily as a basis for assessing any programmatic influences on MEC design and operations.

The schedule, relating to the initial MEC, is shown in Figure 6-4. It indicates that total integration time after delivery of an accepted MEC will be approximately eight months. This time span also is a measure of turn-around time from retrieval of the MEC to relaunch. Its major elements are integration of the MEC with payloads and performance of an integrated system test. More detailed analysis of those operations (see Figures 6-5 and 6-6) showed the elapsed time to be just over six months, based on a five day week, one shift basis. Contingencies could be handled by changing to an extended work week.

Schedule data for manufacturing and MEC integration and test are shown in Figures 6-7 and 6-8 to substantiate the top level development schedule depicted above (Figure 6-4).

These data provide the background for, and will be referred to in the discussion of system verification and test operations in Section 6.4.2.

6.4.2 Verification and Test Operations

6.4.2.1 Verification and Qualification

Preflight verification of the MEC's anticipated operability, reliability, and safety will be established by a combination of analyses and tests. Assurance of these qualities in the flight hardware will depend on the use of the standard services of quality assurance, safety, and the parts, materials and processes disciplines. Verification activities are performed at the parts, components, subsystems, and system level. In the time period of MEC development, it is reasonable to expect that most parts can be selected from highly qualified populations that reflect NASA and DoD space standards. At component level again, very few unique MEC components are anticipated. It is reasonable to assume that the few components in the electrical system, supporting a larger power flow than is customary in spacecraft, will be developed and qualified by the Orbiter program or the Space Platform program. Qualification testing will be necessary for the few components that are MEC peculiar and for those that need to be repackaged or modified for MEC use.

6.4.2.2 System Level Testing

There exists a continuing discussion in the space systems development community as to the most cost effective manner for performing verification testing at system and subsystem levels. Some favor less system level testing

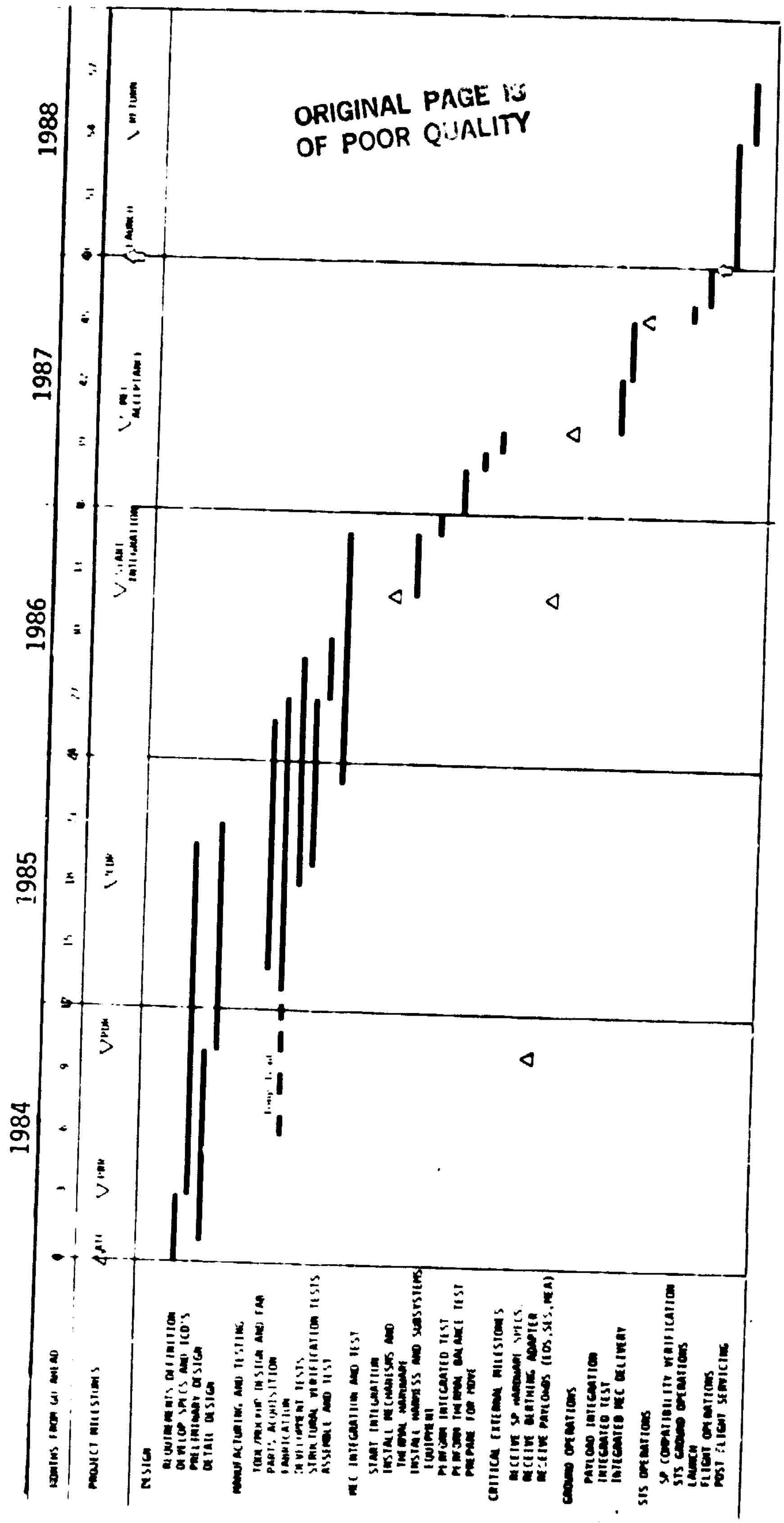


Figure 6-4. Initial MEC Development Schedule

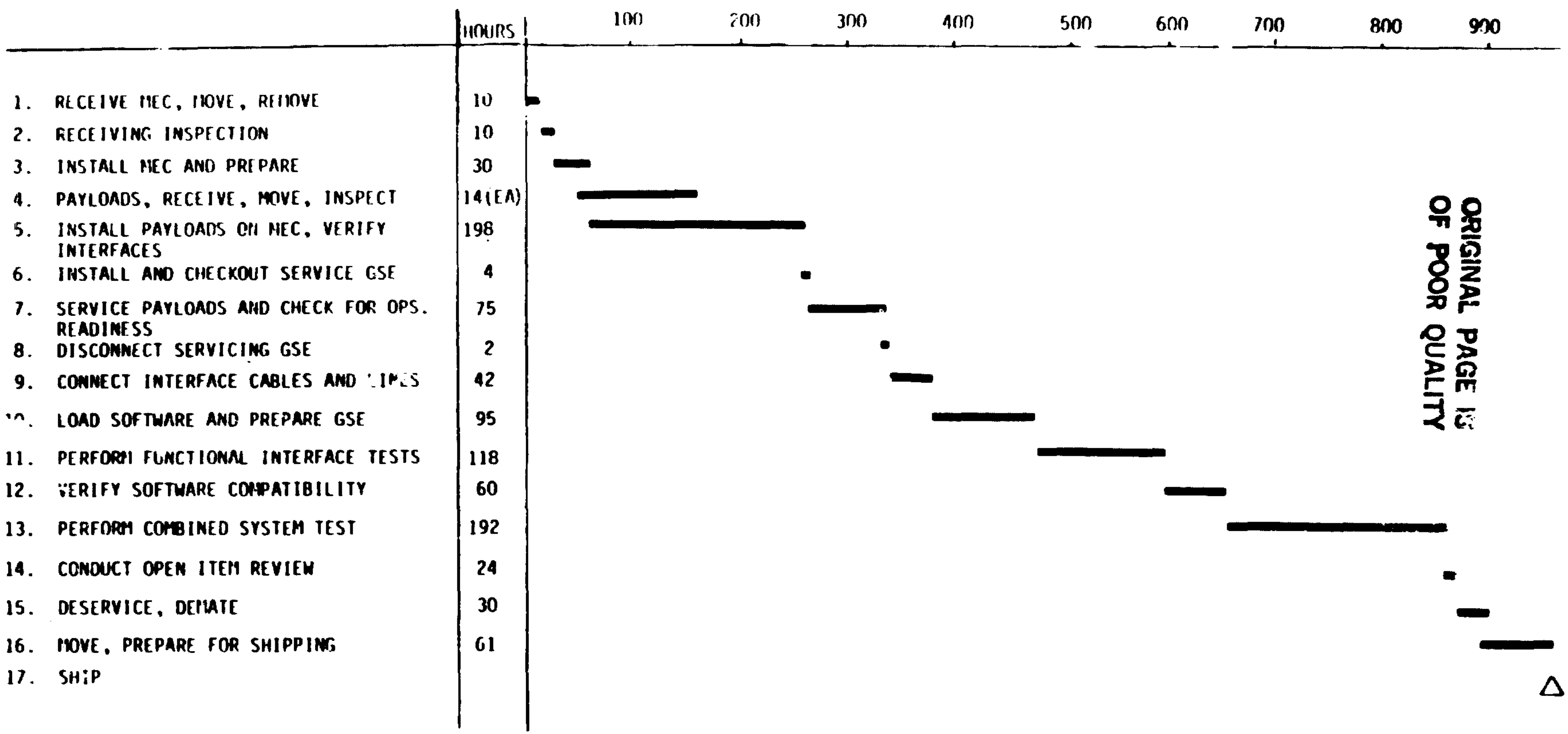
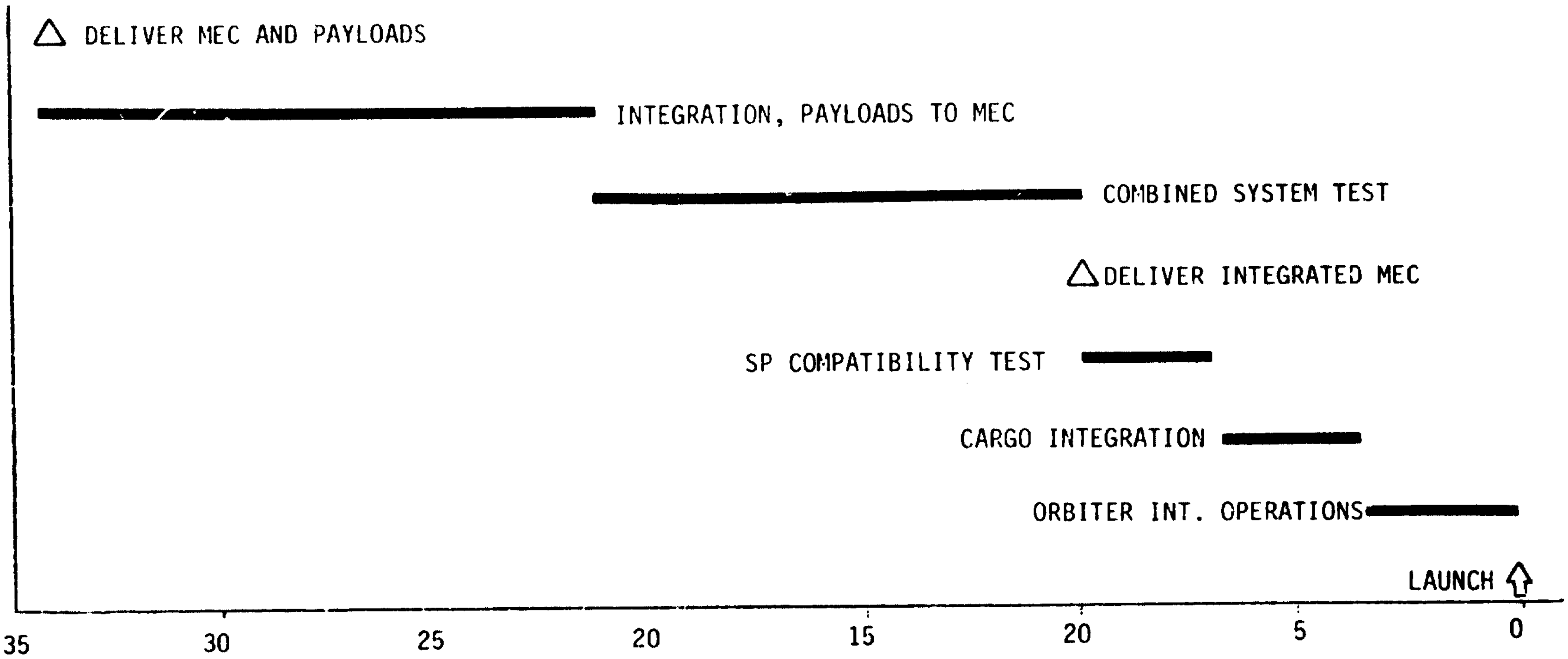


Figure 6-5. MEC Payload Integration and Test Waterfall



Notes:

- o TIMES ARE FOR FIRST MEC OPERATION
- o MEC/PAYLOAD OPERATIONS AT 40 HR/WEEK
- o STS OPERATIONS USE 80 HR/WEEK

Figure 6-6. MEC Ground Operations

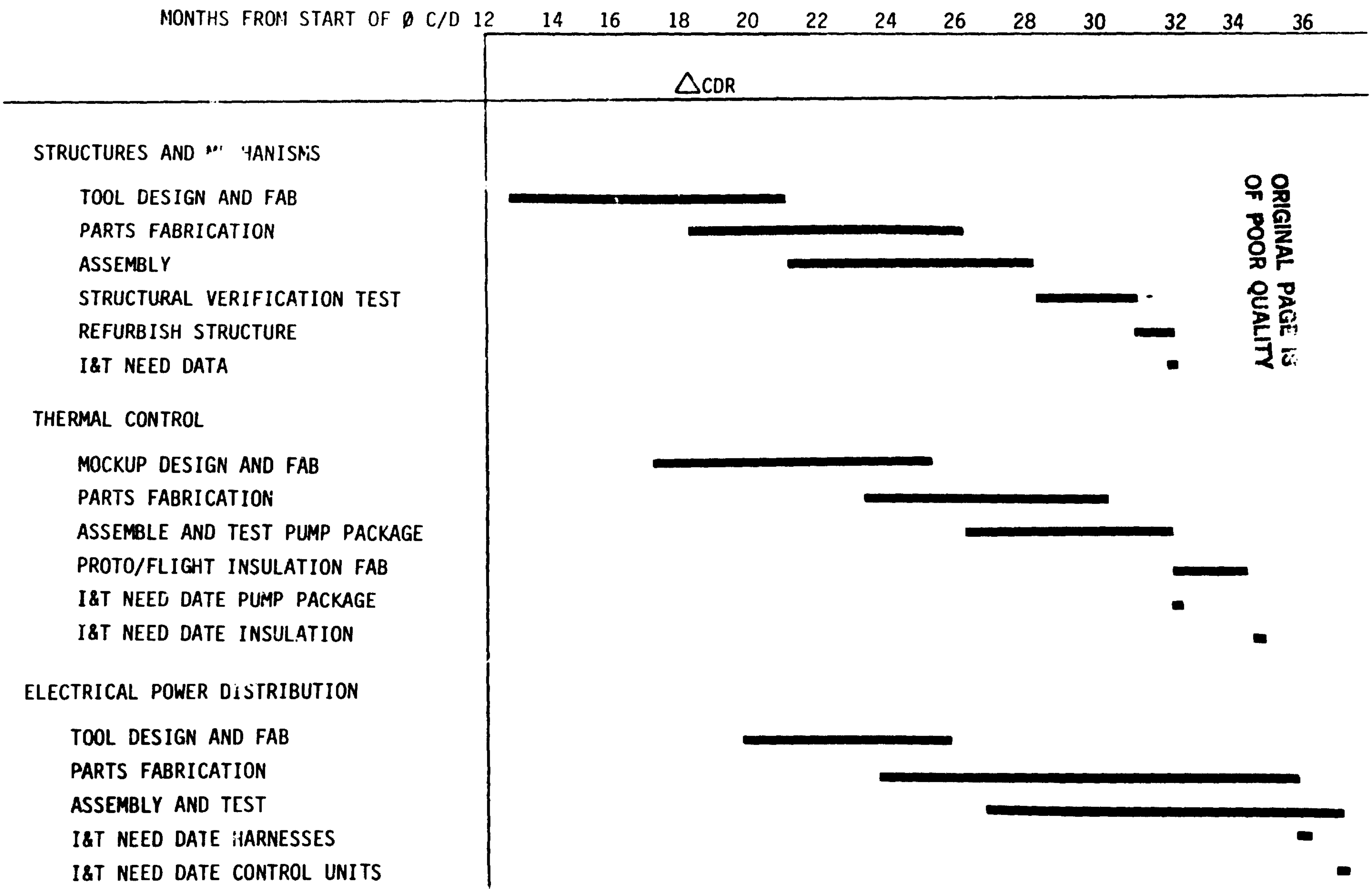


Figure 6-7. Manufacturing

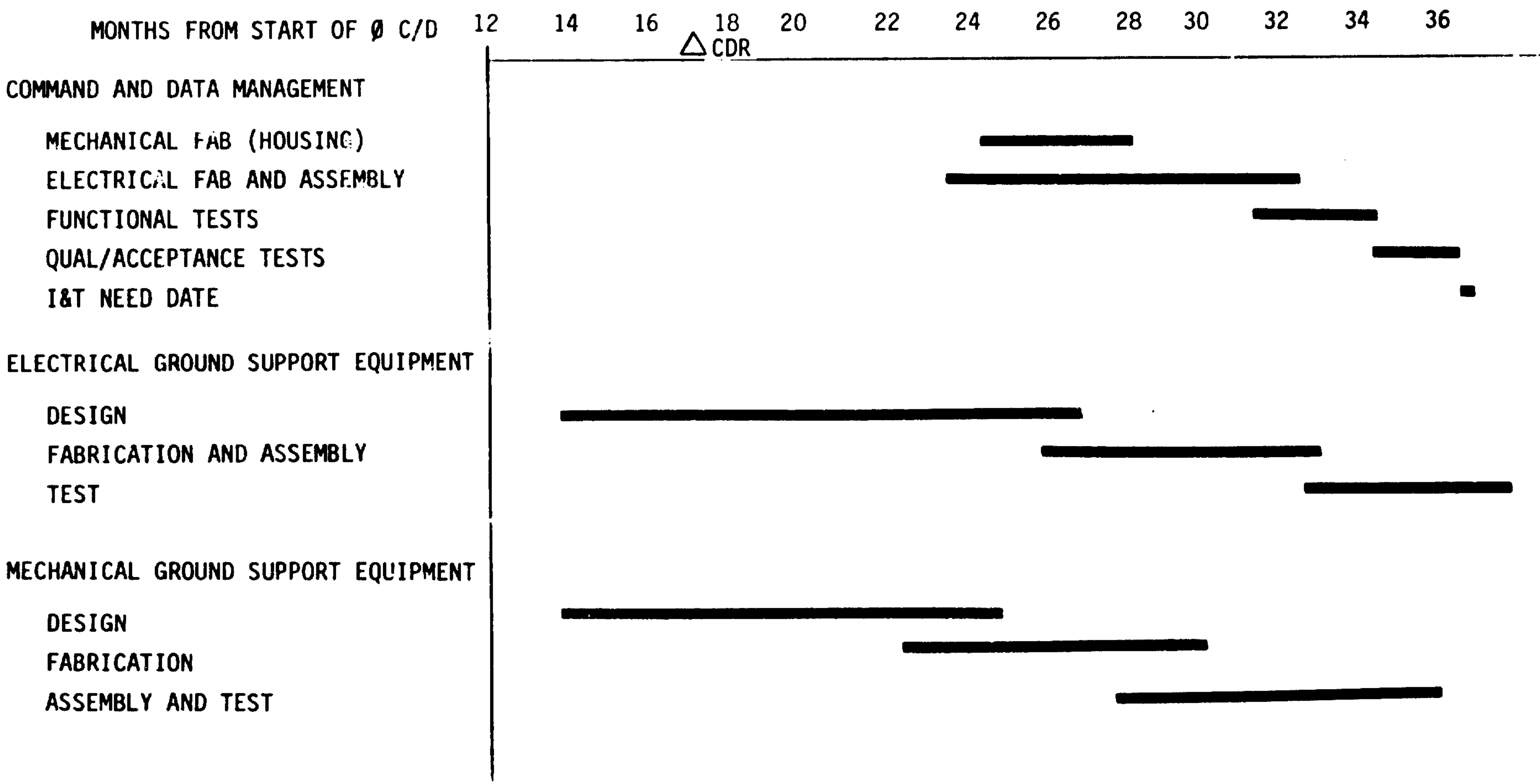


Figure 6-7. Manufacturing (Continued)

	ACTIVITY	DAYS
1.	RECEIVE AND SET UP STRUCTURE	7
2.	INSTALL BERTHING ADAPTORS	5
3.	INSTALL COLDPLATES. TCS PLUMBING, PUMP PKG.	43
4.	PROOF PRESS. AND SNIFF TEST	8
5.	INSTALL HARNESS	12
6.	MOVE TO ENVIRONMENTAL AREA	2
7.	VIBRATION AND PRESSURE TEST	7
8.	MOVE TO I&T AREA	1
9.	INSTALL SUBSYSTEM EQUIPMENT	14
10.	HOOK UP GSE, SERVICE TCS	5
11.	POWER UP FOR TELEMETRY CALIBRATION	4
12.	PERFORM INTEGRATED MEC SYSTEMS TEST	15
13.	EMC TEST	5
14.	INSTALL THERMAL BLANKETS	4
15.	THERMAL BALANCE TEST	10
16.	REMOVE THERMAL BLANKETS	2
17.	LEAK AND FLOW TEST	5
18.	WEIGHT AND C.G. DETERMINATION	5
19.	DESERVICE AND PREPARE FOR SHIPPING	5
20.	SHIP	0

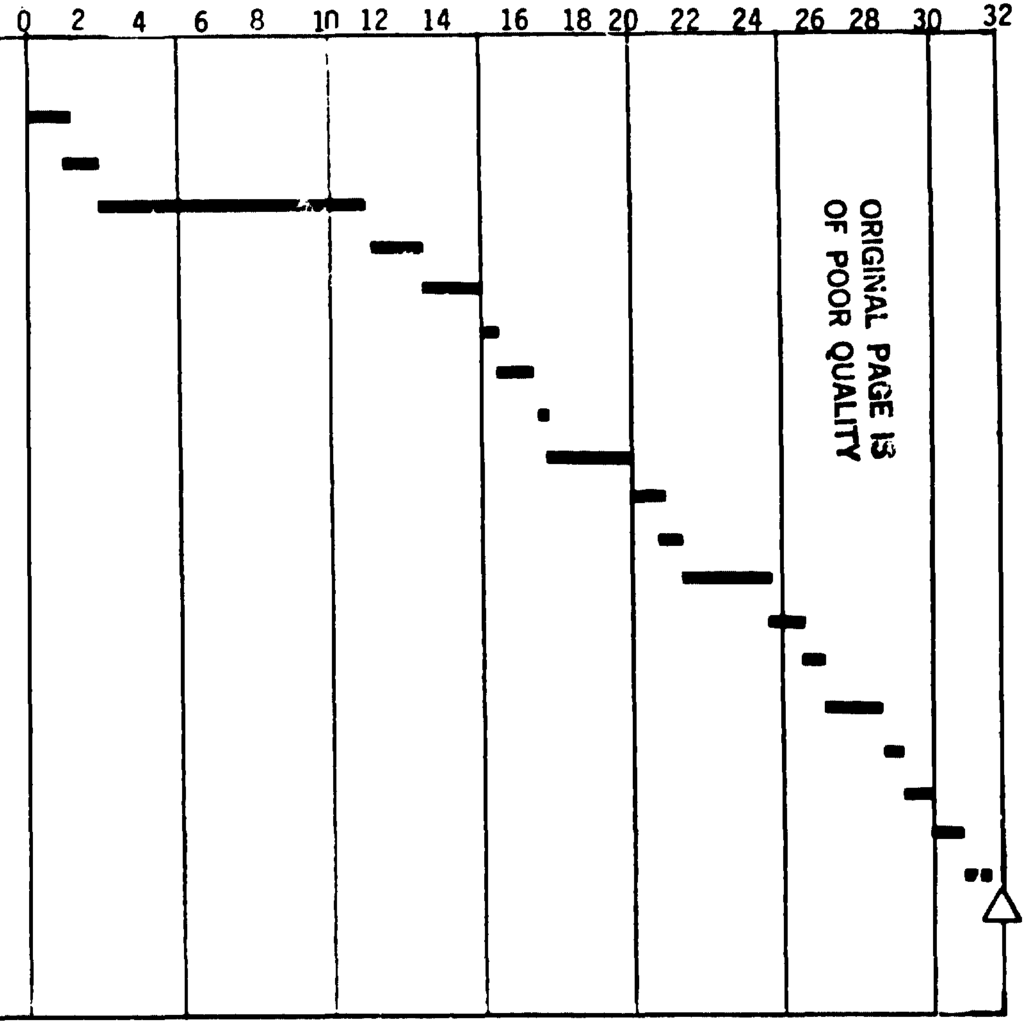


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Figure 6-8. MEC Integration and Test Waterfall

but more testing at the subsystem level. An example cited is the large cost of full system level thermal-vacuum testing. Others argue that, as experience has shown, many failures are induced and detected in system level tests, particularly in thermal-vacuum tests, even after thorough subsystem testing. The argument is academic in the general case, as no one has ever measured the operational effectiveness of a specific regimen of testing. In MEC development we propose a set of tests at both levels, tailored for each subsystem (1) to the particular requirements placed on MEC and (2) to the expected maturity of the equipment to be used. Because these tests influence design, schedule and costs they are discussed here in context with the schedules of specific activities. The relationship of each activity to the initial MEC development schedule is shown in Figure 6-4.

6.4.2.3 Structure Testing

It is proposed that the MEC be developed using the protoflight concept wherein major development tests are performed using flight hardware thus saving the cost of design and construction of test articles. With this concept the tests to establish adequacy of the MEC structure would be performed using the flight structure. As part of the manufacturing, assembly and test activities the flight structure would be subjected to a modal survey test, using dummy masses for subsystems and payloads, and to static load tests. It would be refurbished as necessary prior to delivery for integration of subsystems. Scheduling for this test is shown on Figure 6-7 which depicts the manufacturing schedule for all subsystems and for all of the ground support equipment required for the initial MEC.

6.4.2.4 Thermal Testing

It will be noted that only the active components (the pump package) of the thermal control subsystem will be tested at this level. The thermal control subsystem as a whole would be assembled and tested during MEC integration as shown in Figure 6-8. The other subsystems will be functionally tested at subsystem level.

Figure 6-8 "MEC Integration and Test Waterfall" shows that an all-up system level thermal-vacuum test is not proposed. The simplicity of the initial MEC and its operational modes and the maturity of the proposed hardware, make this test expendable, thus permitting major cost savings. Four

other all-up systems tests would be performed, and under laboratory ambient conditions: the integrated system test, the thermal balance test, the combined system test with payloads (see Figure 6-5) and the SP compatibility test (see Figure 6-6). Two of these will be performed prior to buy-off of the MEC, the other two before each flight. A thermal balance test, performed in ambient air pressure, should adequately characterize that system's capabilities. The large range of cooling throughput designed into the active system makes it possible to tolerate a less precise understanding of the performance of the passive thermal control components.

6.4.2.5 Payload and SP Compatibility Testing

The nature of the MEC (and the Space Platform) as a multiple-use system requires that special compatibility testing of the payloads be performed prior to their meeting with the MEC at integration. It is proposed that a MEC simulator be included in the MEC project. This simulator is to be used in testing payloads off line. Figure 6-5, which details a payloads to MEC integration and testing schedule, is predicated on previous compatibility verification of the payloads. These operations, together with STS ground operations are shown in Figure 6-6. A comparable test is shown for MEC to Space Platform compatibility. It is understood that the SP program will include development of an SP simulator for this purpose.

6.4.2.6 MEC Turn-Around Time

It should be noted that MEC ground operations, overall, use about 8 months which is more than the postulated SP revisit cycle. In this schedule no time is blocked out for modification or refurbishment of the MEC between flights; however, some time will be gained after repeated performance of the integration activities. Also, the MEC/payloads integration could go to multiple shifts if needed. Nevertheless, the MEC design must recognize the fact that the ground operations schedule between flights will always be tight. Careful delineation of these activities will be necessary during Phase B of the MEC project, after more detailed design data are available and early payloads are firmly defined.

6.4.2.7 Ground Operations Maturity

Time periods for all MEC integration activities (Figures 6-5 and 6-8) are estimated for a first-time operation. The STS operations times shown

reflect some ground operations maturity. KSC detailed scheduling (through 1984) for non upper-stage payloads quickly converges to the following intervals for cargo operations and Shuttle launch preparations, together:

- Spacelab seven weeks,
- Other pallets five weeks
- LDEF four weeks

The seven week duration of STS operations was taken for MEC.

6.4.2.8 <u>All-Up MEC</u>

The verification and test philosophy discussed previously should apply equally to the all-up MEC. Details and durations of the integration activities will change considerably. This partly because more payload positions will be available, thus complicating integration. On-orbit changeout of payloads will simplify physical integration on the ground but require that compatibility testing be more thorough as some payloads will meet MEC for the first time on orbit.

6.4.3 <u>MEC Integration and Checkout Activities in Prelaunch Phases</u>*

MEC integration and checkout activity flow in the prelaunch phase will include the following:

(1) Integration and checkout of MEC system at contractor site

(2) MEC/payload integration and checkout at integration site (not necessarily at the same location as the MEC integration site)

(3) Shipment to launch site

(4) MEC/payload integration into Shuttle Orbiter at the launch site

The overall MEC integration, checkout and operation sequence to be followed from prelaunch assembly, and Shuttle integration through launch, orbital operations and retrieval is depicted in Figure 6-9. Ground support equipment (GSE) will be involved in the first ten steps of this sequence. An operations timeline for MEC-payload integration and checkout is shown in Figure 6-5.

The GSE to be used in integration and checkout at the contractor's facility and at the MEC/payload integration site will consist of mechanical support equipment such as transporters, fork lifts, hoists, handling fixtures

*See Also Reference 7, Section 6

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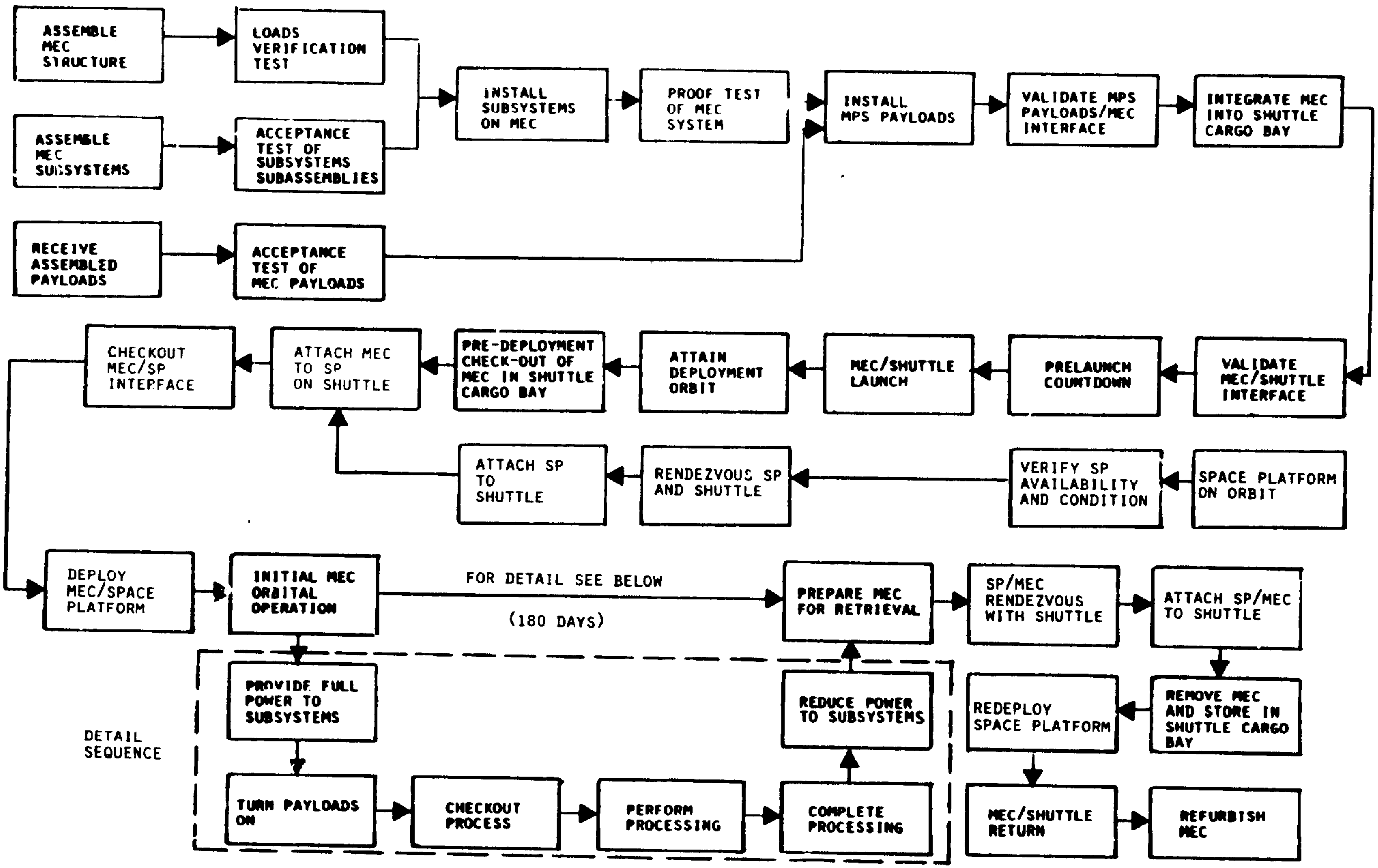


Figure 6-9. Integration, Checkout and Operation Sequence (Initial MEC Mission)

and checkout stands; and electrical support equipment including power supply, checkout consoles, computers, data processors, and recorders. Some of these items will be MEC program unique support equipment that can be used both at the integration sites and the launch site to save cost.

MEC unique support equipment may be shipped to the launch site after completion of integration and checkout activities at the integration facility. However, the need for periodic re-use in subsequent MEC prelaunch activities will probably make use and retention of duplicate equipment at each location more cost effective.

Shipment of the integrated MEC/payload system to the launch site will preferably be via air cargo carrier.

6.4.4 Launch Site Processing

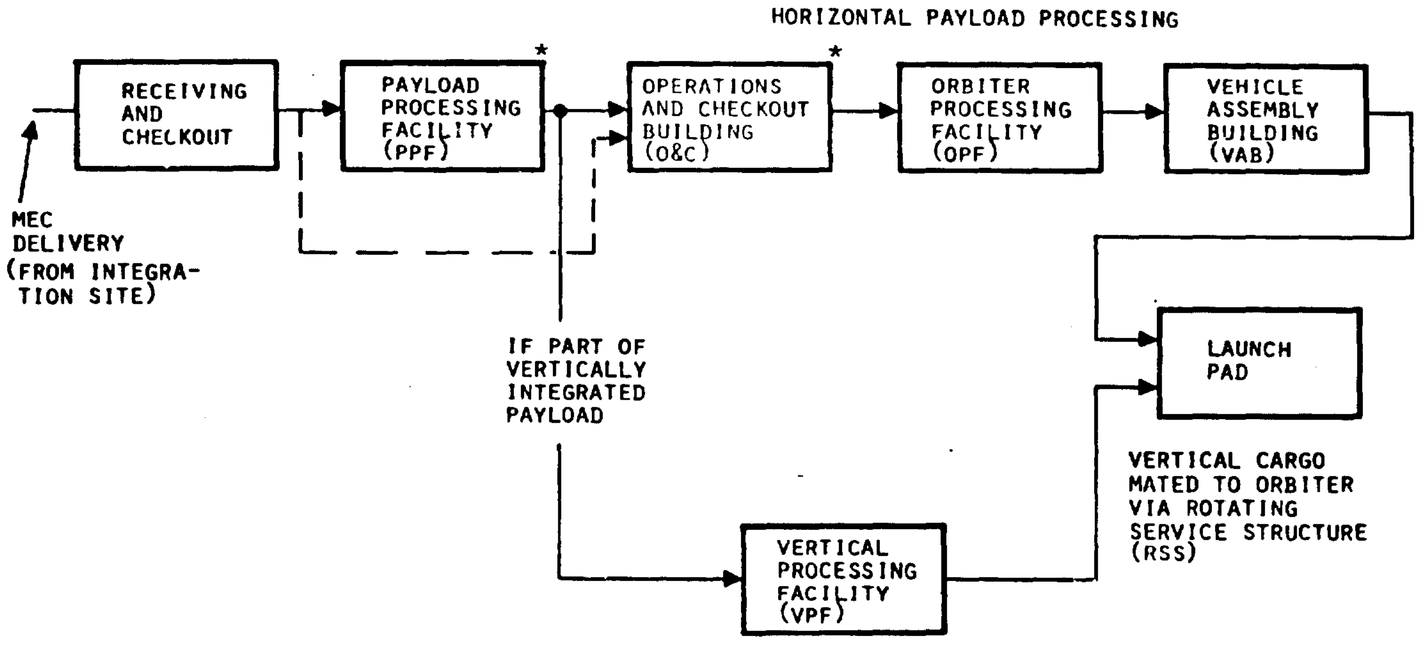
MEC will be accommodated and processed by standard launch site payload handling, checkout and integration facilities in accordance with the procedures described in the Launch Site Accommodations Handbook, NASA K-STSM-14.1 (Reference 18).

For the purpose of this discussion, use of KSC payload processing and integration facilities is assumed, inasmuch as the initial MEC missions and many of the later ones will be flown from that launch site. For MEC missions to be launched from VAFB, the prelaunch processing will be similar in most respects.

MEC processing at the launch site will proceed according to previously prepared and approved plans, procedures and schedules which incorporate specific inputs regarding MEC system and mission interface requirements.

Any MEC-related specific work requirements, problem resolutions, hardware adjustments and tests which are deferred from off-site integration will be identified as early as possible for incorporation into work-around planning and scheduling to avoid impact to on-line STS processing.

As illustrated in Figure 6-10, MEC processing will start with delivery of the MEC and its payload units at one of KSC's automated Payload Processing Facilities (PPF), followed by receiving inspection and checkout. Processing at this facility may require the use of MEC-peculiar GSE to be furnished by the contractor. Significant cost savings can be achieved by minimizing MEC processing requirements at the PPF.



*MEC/SP INTERFACE TEST EITHER IN PPF OR O&C BUILDING

Figure 6-10. MEC Routing and Processing Alternatives at Launch Site

An alternative MEC routing option starts with delivery of the incoming MEC directly to a processing facility downstream of the PPF, where integration of the MEC with other Orbiter payloads will be performed.

Payload receiving functions such as off-loading from the carrier, post-shipment cleaning, removal of covers and transfer to the work site will be supported by general purpose GSE provided by KSC.

6.4.5 Horizontal vs. Vertical Shuttle Payload Integration

The assembled MEC plus MEC payload will be transported from the PPF facility to one of the two payload integration facilities next in line (unless it is delivered directly to that facility, as discussed above) where the Orbiter cargo is assembled, see Figure 6-10. Whether MEC is to be routed to the Operations and Checkout (O&C) Building, for horizontal processing, or to the Vertical Processing Facility (VPF) will depend on the composition of the particular Shuttle cargo to which MEC is assigned:

- The horizontal integration mode will be used if MEC is to be launched together with a sortie payload such as Spacelab or with other free-flying payloads that do not require the use of an upper stage.
- The vertical integration mode will be used if the cargo includes a payload (or payloads) carrying upper stages such as IUS or SSUS.

The integrated Orbiter payload will then be transported in an enclosed canister, either horizontally or vertically to the facility next in line where installation into the Orbiter cargo bay will be performed, i.e., either the Orbiter Processing Facility (OPF) or the Launch Pad/Rotating Service Structure (RSS).

The choice of horizontal or vertical MEC/Orbiter integration will depend largely on the type of companion payload assigned to share the Shuttle launch with MEC. This means, that MEC must be compatible, in terms of configuration, handling and interface design characteristics, with both of these Orbiter/payload integration modes.

This requirement does not impose major constraints on the MEC configuration but will affect the MEC/Orbiter and MEC/GSE interface design with regard to location and accessibility of the MEC/Orbiter umbilical. In addition, the required compatibility of MEC with different processing facilities and procedures may impose restrictions on payload access during prelaunch preparations.

6.5 ON-ORBIT SERVICING

6.5.1 Objectives

On-orbit servicing will be required in all-up MEC missions to increase mission cost effectiveness, by

- Extending mission duration and thus increasing mission output, i.e., the number of samples processed per mission,
- Reducing the number of MEC launches and retrievals required per year, thereby greatly reducing transportation costs,
- Achieving improved payload/mission matching, and more effective Space Platform utilization by MEC, e.g., through replacement of payload units that complete their mission objectives ahead of others.

Servicing is not projected on initial MEC missions (a) to simplify the design and thus save initial MEC development cost, and (b) because Shuttle revisits to the Space Platform are projected to occur only twice per year. An orbital stay time of 180 days, conforming with this schedule, is considered sufficiently long for any initial MEC mission so that on-orbit servicing would not even be useful. Most of the considerations discussed in this section therefore will apply to the all-up MEC only.

MEC payloads will have design interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations will include exchange either of entire payload units or only of sample magazines within payloads, but also, possibly, maintenance, repair or replacement of system elements if required. Figure 6-11 compares objectives and design implications of payload changeout vs. sample changeout.

6.5.2 Mission Scenarios With and Without Servicing

Four principal scenarios are illustrated in Figure 6-12. The first, third and fourth of these do not permit or require on-orbit servicing, the second envisions servicing to aid in extending on-orbit operation beyond the projected six-month interval between successive Orbiter visits of the Space Platform. A different mission concept without on-orbit servicing, illustrated in scenario four, foresees alternate launches of two MEC vehicles. One vehicle is refurbished on the ground while the other is in orbit.

Results of an analysis performed to determine the comparative advantages of missions with or without servicing capability are listed in Table 6-2.

OBJECTIVES

Payload Changeout

- Matching of payload productivities
- Orbital accommodation of new or additional payloads at favorable times

Sample Changeout

- Early sample return for analysis on ground
- Limited sample shelf-life in orbit: biologicals

MEC/PAYLOAD DESIGN IMPACT

Payload Changeout

- Autonomy of payloads
- Simple payload attachment, interfaces
- Ease of on-orbit access and handling
- Interchangeability
- Ruggedness to withstand handling

Sample Changeout

- Accessible/removable storage magazines
- Unobstructed access into enclosures
- Protective sample enclosure required
- Crew hazard avoidance in access, handling

Figure 6-11. Objectives and Design Implications of Payload and Sample Changeout On Orbit

6.5.3 Rationale for On-Orbit Servicing

On-Orbit servicing of the all-up MEC permits extension of the mission duration which will be desirable or essential for certain types, e.g., float zone processors, while other payloads that require less time in orbit can be replaced.

Principal factors favoring on-orbit servicing are the need for fewer launches of the large all-up MEC vehicle, saving transportation and ground refurbishment costs, and greater mission flexibility. There are, however, several other factors which tend to limit the potential cost savings, such as: the extra cost of providing MEC with serviceability features; more complex operations during SP/MEC revisits; and the procurement and repeated launch of a separate payload carrier (Service Support Assembly).

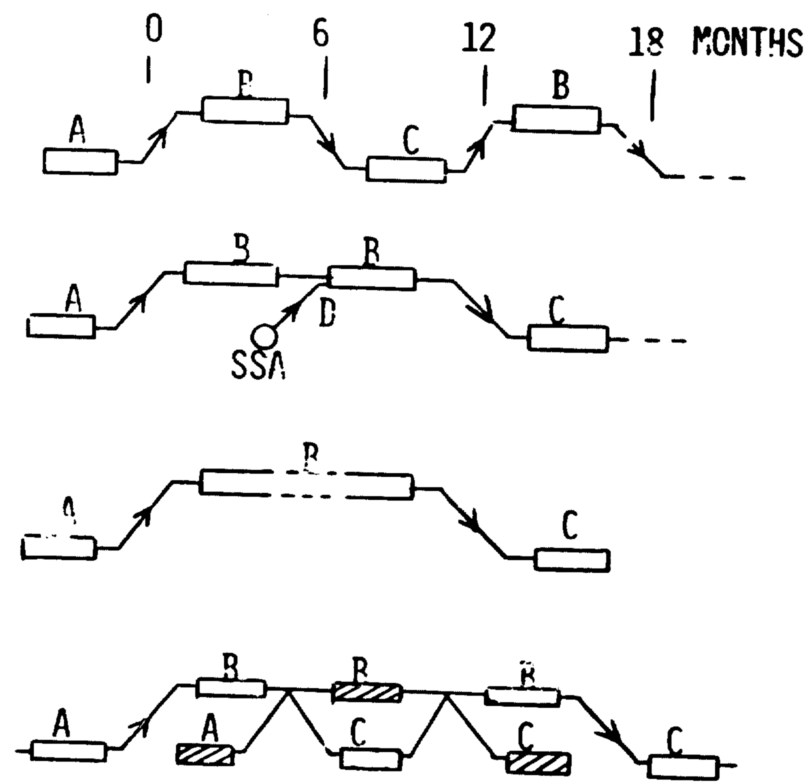
Preliminary assessment has shown that the advantages of the on-orbit servicing option outweigh its disadvantages and support the decision to provide MEC with the design features required for serviceability. Further assessment of these factors and their impact on system design, mission profile definition and program cost is discussed below.

1. INITIAL MEC
   - NO SERVICING
   - RETRIEVE AFTER 6 MONTHS

2. ALL-UP MEC (1 UNIT)
   - SERVICE AFTER 6 MONTHS

3. ALL-UP MEC (1 UNIT)
   - NO SERVICING
   - RETRIEVE AFTER 6 OR 12 MONTHS

4. INITIAL OR ALL-UP MEC (2 UNITS) IN INVENTORY
   - NO SERVICING
   - ALTERNATE LAUNCHES EVERY 6 MONTHS



LEGEND:

A - P/L INTEGRATION
B - ON-ORBIT OPERATIONS
C - REFURB. ON GROUND
D - RENDEZVOUS AND P/L EXCHANGE

NOTE: PROJECTED 6 - MONTH STS LAUNCH INTERVAL IS REFLECTED IN EACH OF THESE SCENARIOS. SCENARIO 1 AND 4 KEYED TO 6 MONTH REFURBISHMENT/TURN AROUND TIME ON GROUND. INCREASE TO 8 MONTHS WOULD REDUCE REFLIGHT FREQUENCY.

Figure 6-12. Mission Scenarios With and Without Servicing

Table 6-2. Servicing Vs. No Servicing (All-Up MEC Only)

	ADVANTAGES	DISADVANTAGES
(A) NO SERVICE-SINGLE MEC	• SIMPLER DESIGN • SIMPLER DEPLOYMENT TASK • NO SERVICE SUPPORT ASSEMBLY • LESS ASTRONAUT TRAINING	• LESS MISSION AND PAYLOAD DEPLOYMENT FLEXIBILITY THAN (B) AND (C) • MISSION DURATION GENERALLY CONSTRAINED TO 6 MONTHS, IMPACTS PRODUCTIVITY
(B) NO SERVICE-TWO MEC'S*	• SAME AS ABOVE, PLUS • OBTAIN MORE PAYLOAD ORBIT TIME THAN IN (A), I.E., MORE FLIGHT OPPORTUNITIES (CONSISTENT WITH RAPID INCREASE IN NUMBER OF P/L CANDIDATES)	• NEED ADDITIONAL MEC UNIT • HIGH NUMBER OF LAUNCHES DRIVES UP COST • NOT AS COST EFFECTIVE UNLESS LARGE P/L FLIGHT DEMAND BACKLOG
(C) SERVICING-SINGLE MEC	• OBTAIN MORE P/L ORBIT TIME THAN (A) WITHOUT FREQUENT MEC RELAUNCH AS IN (B) • GREATER FLEXIBILITY - P/L MIX - MISSION DURATION - P/L DEPLOYMENT STATUS • REDUCE COST PER KW-HR	• COST OF SERVICE SUPPORT ASSEMBLY • EXTRA COST OF CREW TRAINING, EXTENDED SORTIE DURATION • EXTRA COST OF SERVICEABILITY • EXTRA COST OF SSA • EXTRA COST OF GROUND SIMULATOR

*This scenario adversely affected if ground refurbishment/turn around time would be 8 rather than 6 months, resulting in one-year reflight intervals due to projected SP revisit schedule by Shuttle

C-3

A cost comparison was performed of two principal mission options, either using a single MEC with servicing on orbit (scenario 2 in Figure 6-12) or two MEC's at alternate launch opportunities every 6 or possibly 8 months (scenario 4). The normalized cost per year in orbit for scenario 4 will be only slightly larger than that for scenario 2, i.e., about 10 percent. This is due largely to the cost of developing and flying a Service Support Assembly in scenario 2 but not in scenario 4. This cost difference alone is not sufficiently large to provide a basis for adopting the servicing mode, scenario 3. The impact of 8 rather than 6 month ground turn around time on the scenario also should be taken into account. Secondly, an imporant qualitative difference, not reflecting in cost figures, is the fact that scenario 4 is limited in orbital stay time per mission which may not be satisfactory for certain payloads.

For a further explanation of this issue, consider the three MEC user populations characterized in Figure 6-13 by their probability distribution vs. desired orbital stay time. In population ① a majority of the users require short stay times, around three months. This peak shifts in distribution ② and ③ to four and five months, respectively. This trend may be assessed as follows:

1. Payload requirements analyses in study Part 1 indicate that distribution ② is representative of potential MEC user population. (All-up MEC).
2. Orbit stay time = (processing time) x (desired sample number).
3. Increase in sample number to reduce cost/sample drives stay time up.
4. Emphasis on commercial users also drives stay time up (e.g., EOS).
5. MEC planning should address items 3 and 4, therefore reflect distributions ② or ③ rather than ①.

Based on these factors and a projected six month revisit interval, MEC stay time extension beyond the six-month interval length with changeout of some payloads will often be advantageous. In this manner one can satisfy users with less than six-months and those with more than six-months desired stay time equally well.

6.5.4 Impact of On-Orbit Servicing Requirement on Configuration and Mission Operations

Table 6-3 lists design features required for making MEC payloads or sample magazines replaceable on orbit. These features include not only special provisions for payload access, mounting and demounting, and for mating

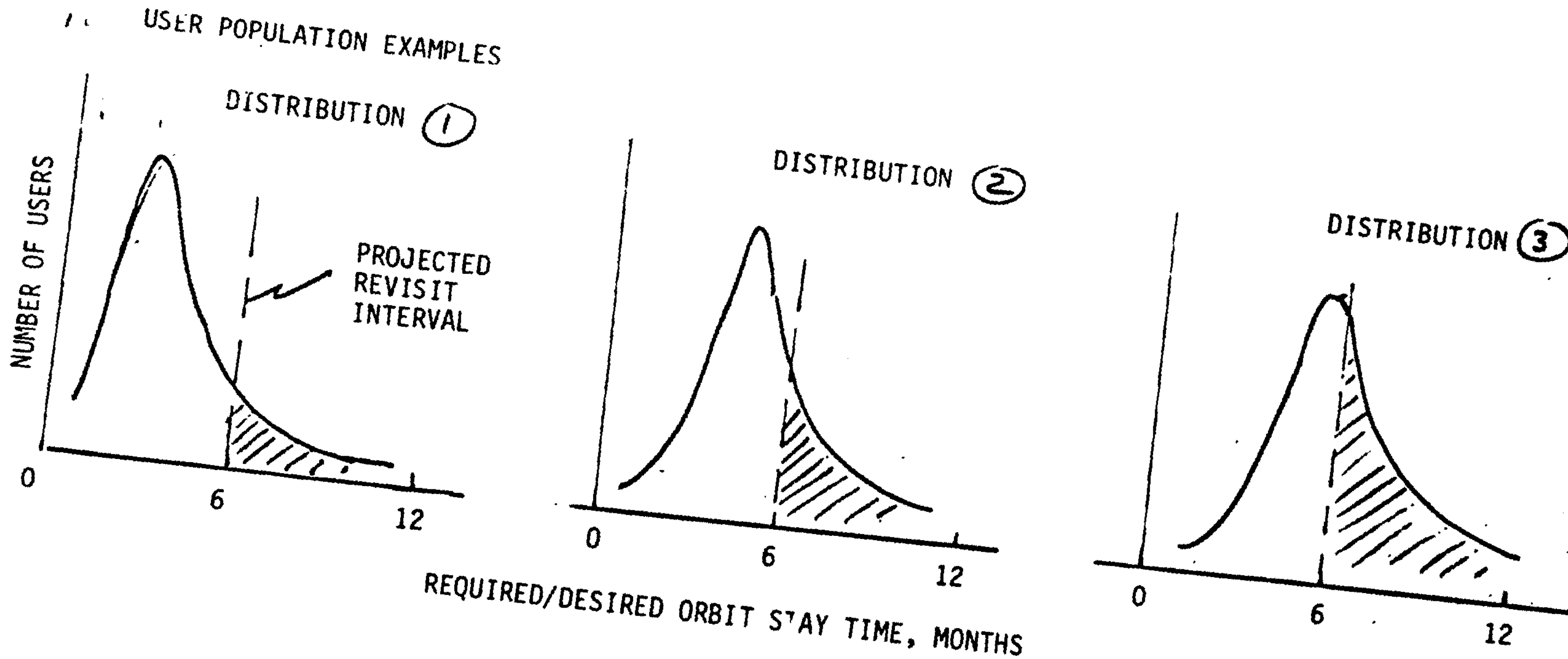


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Figure 6-13. Orbital Stay Time Criteria (All-Up MEC)

or demating of electrical and fluid line connectors but also the overall configuration layout. Serviceability also reflects in the arrangement of the EOS payload relative to the MEC core and growth modules, so as to permit unobstructed access to MEC payload compartments. Note that these serviceability design features do not include provisions for on-orbit repair or replacement of failed units, which would further complicate the design.

Table 6-3. Impact of On-Orbit Servicing Requirement on Configuration*

1.	Axial payload attachment in core module (retained in all-up MEC) requires location at growth module aft end.
2.	Also requires EOS attachment via hinged adapter.
3.	Extra cable and coolant line length from SP to MEC subsystems because of aft end mounting of core module (which contains subsystems).
4.	Lateral payload access in growth module dictated by location between SP and core module.
5.	Growth module payloads rail-mounted to facilitate on-orbit changeout. (Sample changeout access requires further study).
6.	Use of MMS-type/SP-type electrical connectors, quick-disconnects for coolant, guide pins and lead screws for mating/demating of payloads.
7.	Provisions in initial MEC payload interfaces to permit conversion to on orbit mating/demating capability (item 6).

*In all-up MEC only

Serivicing operations require payload and component handling either by the Shuttle Remote Manipulator System (RMS) or manually, by a crewman in the EVA mode. The payload units must provide grapple fixtures and/or handles for manipulation by the RMS or crewman. In addition, convenient and safe access to internal equipment must be provided via access hatches of sufficiently large size. Crew servicing also will require access support provisions on payload units and on the MEC proper, such as handholds, handrails and foot rests.

Utilization of the Teleoperator (TMS) to perform remote MEC servicing functions by transferring payloads between the Orbiter and the SP/MEC will be an alternative to Orbiter-based servicing (see Section 6.2). A principal advantage of this mode is the avoidance of SP/MEC proximity operations and berthing and consequently, any interference this may cause with Orbiter mission objectives other than MEC servicing. Also there would be no need for carrying a SP berthing adapter.

6.6 EFFECTIVE SHUTTLE UTILIZATION

6.6.1 Shuttle Transportation Cost Economy

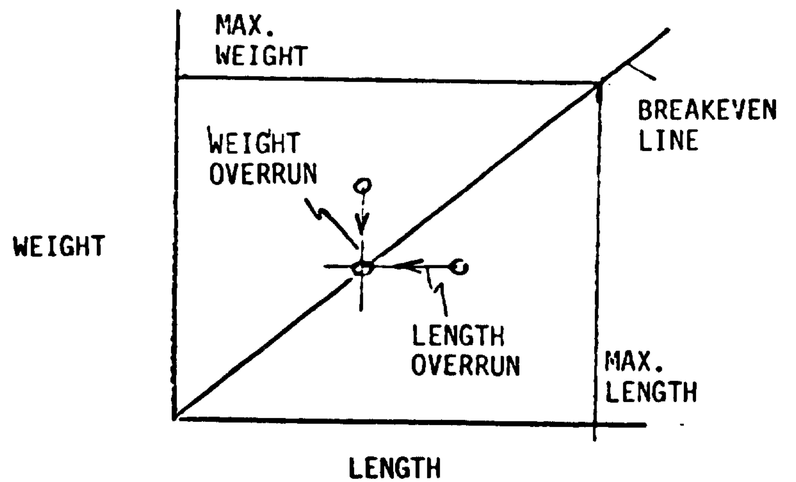
Shuttle transportation economy is a principal criterion in MEC design and mission planning. Accordingly, MEC configuration selection and sizing should be keyed to cost effective Shuttle accommodation such that total chargeable length and weight, for STS transportation, will be close to the length/weight breakeven ratio. Weight variations due to changeable payload complements generally may cause deviations from the ideal weight/length ratio of Shuttle cargo capacity. Compatibility with other Shuttle payloads in a mixed cargo launch situation, however, will make such deviations a matter of secondary concern.

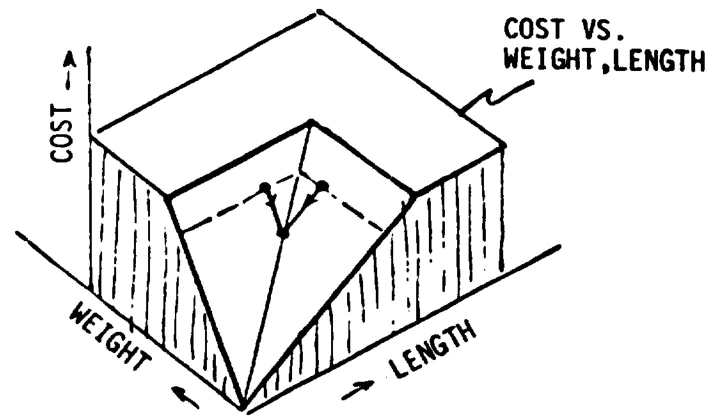
Analysis has shown that very short structures, such as the 30-inch MEA type spoked disc, tend to be weight critical when loaded with payloads. Therefore, every effort should be made to minimize structural and subsystem weight.

Additional factors pertaining to NASA's Shuttle launch cost policy for shared missions (Reference 19) are summarized in Figures 6-14 and 6-15. These illustrations explain key issues involving weight-critical vs. length-critical payload characteristics. Figure 6-14 graphically shows that payloads with weight and length close to the weight/length cost breakeven ratio make the most cost effective use of Shuttle launch capabilities. This ratio is 1080 lb/ft for low-inclination, low-altitude orbits, assuming nominal Shuttle launch weight performance. It decreases at higher orbit inclination and altitude as explained in Figure 6-15.

In the same context, the following factors also are of interest regarding MEC configuration selection and sizing:

1) The cost delta per 1000 lb of weight above the breakeven line is $0.628 mill; the cost per 1 ft of length beyond breakeven is $0.680 mill.
2) As a general rule, payload length should be keyed to an average projected weight, such that any expected weight "overruns" or "underruns" reflect in approximately equal departures from the breakeven point.
3) MEC length underrun may be useful in situations where prospective companion Shuttle payloads tend to be length critical.
4) For example, in a shared launch with the Space Platform, Reboost Module and Test Set MEC can be more readily accommodated as a companion payload, and launch cost reduced if its length is below the breakeven point.





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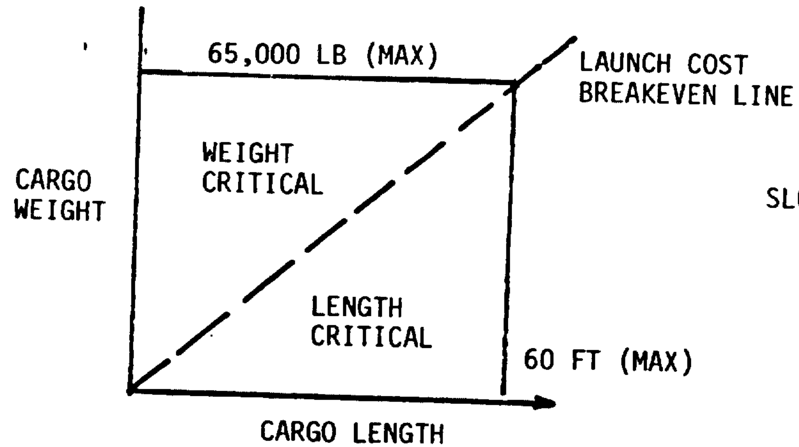
1. BREAKEVEN LINE GIVES MOST WEIGHT FOR GIVEN LENGTH OR MOST LENGTH FOR GIVEN WEIGHT AT COST CORRESPONDING TO THAT LENGTH OR WEIGHT

2. B.E.L. DETERMINES THAT WEIGHT AT GIVEN LENGTH (OR THAT LENGTH AT GIVEN WEIGHT) FOR WHICH LAUNCH COST IS LOWEST

3. WEIGHT OR LENGTH "OVERRUN" IS A MEASURE OF DEVIATION FROM RESPECTIVE COST OPTIMUM

4. THE WEIGHT OR LENGTH MARGIN IS THE AMOUNT OF EXTRA WEIGHT OR LENGTH AVAILABLE AT NO EXTRA LAUNCH COST

Figure 6-14. Breakeven Line Indicates Most Cost Effective STS Launch Conditions



$$\text{SLOPE} = \frac{65000}{60} = 1080 \text{ LB/FT } (28.5^{\circ} \text{ INCL., 200 N.M. ALT.})$$

$$\frac{55000}{60} = 920 \text{ LB/FT } (56^{\circ} \text{ INCL., 200 N.M. ALT.})$$

(FOR NOMINAL SHUTTLE PERFORMANCE)

- **MOST COST EFFECTIVE LAUNCH IS FOR CARGO WEIGHT/LENGTH RATIO CORRESPONDING TO BREAKEVEN SLOPE**
- **FOR AN ASSUMED 13,000 LB MEC GROSS WEIGHT THIS WOULD ALLOW A TOTAL LENGTH OF 12 FT (AT 28.5° INCLIN.), I.E., 2.5 FT GREATER THAN PALLET LENGTH (9.5 FT)**
- **SPOKED-DISC CONFIGURATION LENGTH OF 5 FT* CORRESPONDS TO A BREAKEVEN WEIGHT OF ONLY 5400 LB**
- **CONFIGURATION B LENGTH OF 19 FT FOR ALL-UP MEC WOULD CORRESPOND TO 20,500 LB BREAKEVEN WEIGHT**
- **THUS, CARGO LENGTH GENERALLY LESS CRITICAL TO LAUNCH COST ECONOMY THAN WEIGHT**

*INCL. TWO BERTHING ADAPTERS

Figure 6-15. Shuttle Transportation Cost Economy

NASA encourages matching length-critical (low density) and weight-critical (high density) payloads through private launch-sharing arrangements between users. The incentive for such arrangements, a potentially large cost saving, is built into the launch cost algorithm. At NASA/JSC this strategy is termed matching "fishing poles and cannon balls." Under favorable conditions it can save each user 50 percent or more of the nominal launch cost, by (1) minimizing length or weight penalties and (2) reducing the 33 percent mark-up applying to individually manifested payloads. (For more detailed discussion see Appendix B). Items 3 and 4 in the above list are examples where such launch cost savings might be realized.

6.6.2 MEC Weight and Length Characteristics vs. Transportation Cost

Figure 6-16 shows transportation cost contours versus payload length and weight in $2 million increments (based on a dedicated Shuttle launch of $30.6 million in 1981 dollars). These contours form a set of nested rectangles with the common diagonal indicating the breakeven condition between length and weight dependent user charges. Several smaller cost items other than those related to length or weight are not included in this dicussion.

Shaded bars representing initial and all-up MEC length and weight estimates are loacted above the cost breakeven line, i.e., in the "weight-critical" part of the diagram. The large spread of estimated weight in the all-up MEC is due primarily to upper and lower weight estimates, 1000 and 3000 lb, respectively for four of the payloads that are being carried by the MEC growth module (based on the payload weight survey performed in the MEC study, Part 1). Under these conditions an expansion of MEC length by 2 to 3 ft would not reflect in a significant transportation cost increment.

The second set of bars, shown in dashed outline, indicate estimated length and weight of pallet-based initial and all-up MEC configurations and their respective launch cost. These configurations are length-critical or slightly weight critical.

Table 6-4 lists rough cost estimates for the various configurations considered. The extra transportation costs of the pallet-based initial MEC range from $1.8 to 3.2 million, those of the all-up MEC from $0.8 to 5.5 million.

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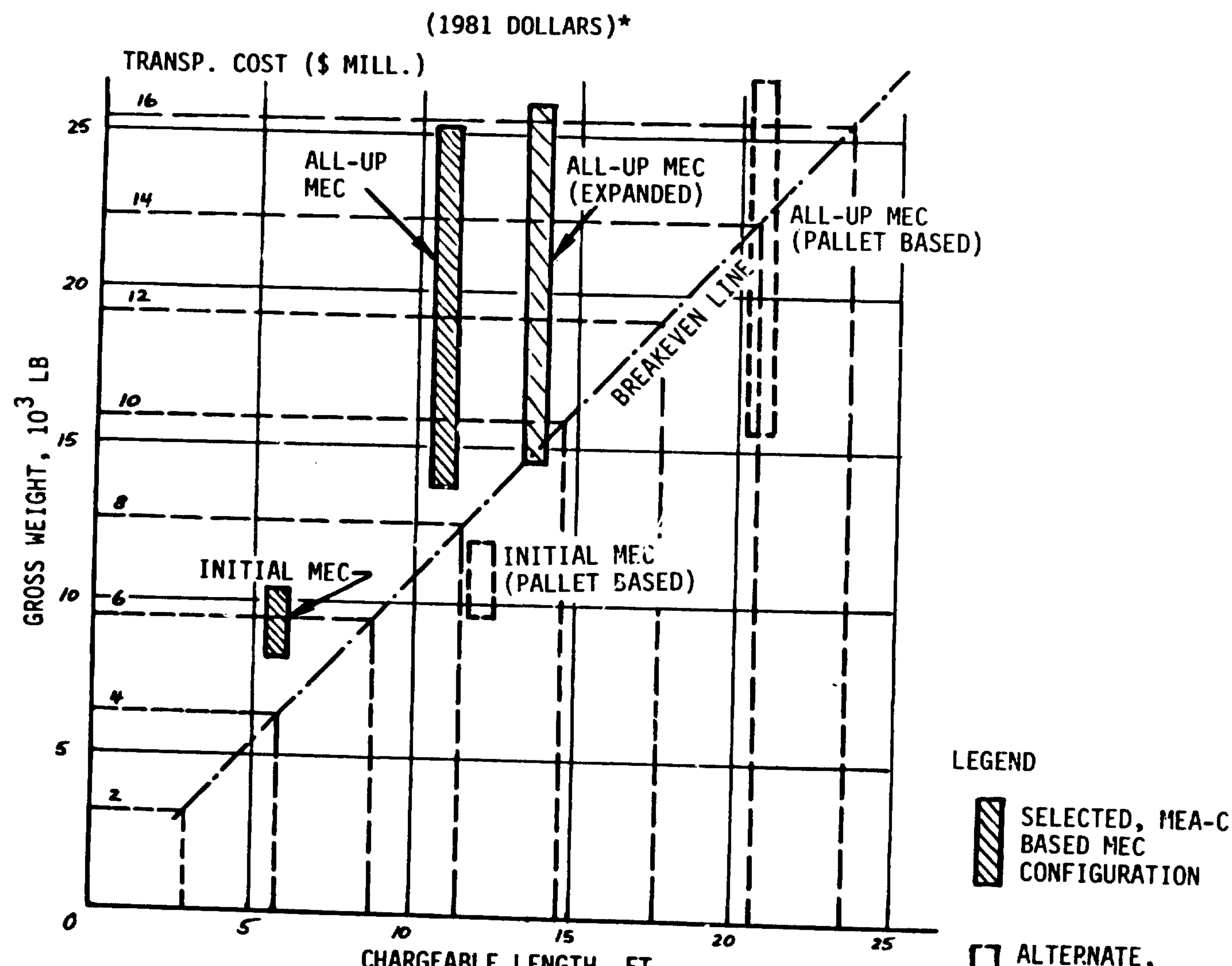


*DEDICATED SHUTTLE LAUNCH COST $30.6 MILLION

Figure 6-16. STS Transportation Costs vs. MEC Length and Weight

Table 6-4. Preliminary MEC Configuration Launch Cost Estimates* ($ Million)

CONFIGURATION OPTIONS	LAUNCH COST DETERMINED BY LENGTH OR WEIGHT	ESTIMATED LAUNCH COST RANGE	EXTRA LAUNCH COST OF PALLET-BASED DESIGN
Selected (MEA-Based)			
Initial	W	5.2 - 6.6	1.8 - 3.2
All-Up	W	8.6 - 15.9	0.8 - 5.5
(Expanded All-Up)	W	(9.2 - 16.4)	0.3 - 4.9
Alternate (Pallet Based)			
Initial	L	8.4	SEE ABOVE
All-Up	L or W	14.1 - 16.7	

*Basic launch cost, excluding user fees, special services etc. Dedicated launch cost is $30.6 million, in 1981 dollars (at 1.698 escalation factor above 1975 dollars, per Reference 19)

6.6.3 Influence of Payload Density, Weight and Volume on Shuttle Transportation Cost

A set of basic quantitative relationships were determined to facilitate assessment of MEC carrier and payload weights, vehicle length and payload densities relative to optimum design characteristics from the standpoint of transportation cost economy. Appendix B presents details of this analysis

In addition to the payload density $\delta = W_{PL}/V_{PL}$ a packing factor $\gamma = V_{PL}/V_{MEC}$ was introduced as parameter for measuring Shuttle cargo space utilization efficiency, where

W_{PL} = payload weight (lb)
V_{PL} = payload volume (ft^3)
V_{MEC} = cargo bay volume used by MEC (net volume excluding adapters etc.) corresponding to net length.

In addition to net volume, and net length, the "chargeable" volume and length are of principal concern. Chargeable length, which includes adapters plus 0.5 ft of clearance between the MEC and other payloads stowed in the cargo bay (3 in. on either side) is typically 3 ft greater than net length for the MEC configurations considered.

Results are presented in Figure 6-17 for quick-look evaluation of relevant MEC design characteristics and their relation with respect to the desired length-to-weight breakeven ratio, assumed here as 1080 lb/ft^3.

This three part nomograph shows the relation between payload density, payload weight and MEC length (lower half), payload fraction and gross weight (upper right) and transportation cost contours vs. length and weight (upper left). The examples shown illustrate that breakeven conditions in length and weight dependent launch cost correspond to the (hypothetical) payload fraction of 1.0 if a payload density of 20 lb/ft^3 is assumed (points P). A payload density of 15 lb/ft^3 would correspond to a payload fraction of 0.8 (points Q).

These factors can also be interpreted to mean that a realistic payload fraction of 0.8 to 0.9 would mean a gross weight above the breakeven condition if a payload density of 20 lb/ft^3 or higher is assumed. Review of density figures derived from the payload survey in the MEC Study, P[illegible] 1 indicates that the prospective payloads generally range in density between 12 and 20 lb/ft^3, with an average of about 16 lb/ft^3. (See Appendix B).

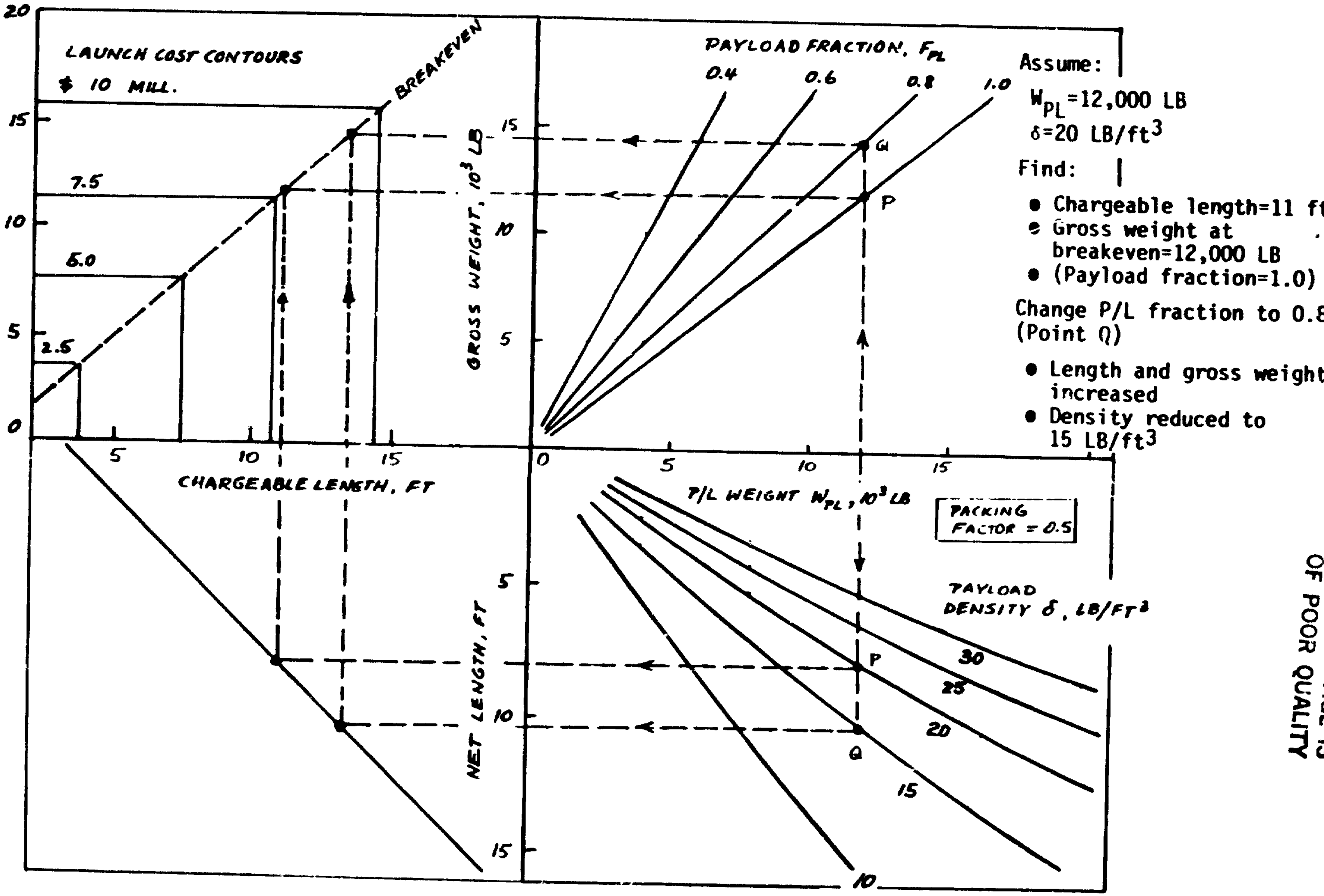


Figure 6-17. Payload Density vs. MEC Length, Weight and Launch Costs

In the above example we also note that the chargeable length of a MEC vehicle with a gross weight of 15,000 lb carrying 12,000 lb of payload weight would be 14 ft at the breakeven point of length and weight charges. For a typical payload density of 20 lb/ft^3 and a packing factor of 50 percent the transportation charges would be determined by weight rather than length, with a margin of about 25 percent. Thus the packing density could be lowered without increasing launch cost.

In the nomograph a packing factor γ of 50 percent is assumed. The quantity which determines the slopes of the lines in the lower right quadrant actually is the product $\delta \cdot \gamma$, termed packing density. If the assumed packing factor is changed to a value other than 50 percent the values of payload density δ assigned to these lines should be changed accordingly so as to leave the respective $\delta \cdot \gamma$ values unchanged.

The above results are significant in terms of weight and length allocations to be considered for the all-up MEC configuration. However, the analysis does not take into account any cost benefits achievable by combining low density with high density payloads, as discussed in the preceding section.

6.6.4 Crew Functions

Orbiter crew functions are an essential part of the mission profile and effective utilization of Shuttle support by MEC. Table 6-5 lists the crew functions required in MEC deployment, retrieval and servicing phases. In the MEC mission and system design concepts described above effective use of intra- and extravehicular crew activities has been emphasized.

6.7 EFFECTIVE SPACE PLATFORM UTILIZATION

6.7.1 Resource Utilization Planning

Limitations of available resources, particularly on the initial 12.5 kW version of SP, demand that all users perform their missions as economically as possible. With MEC generally being the user that consumes the largest share of available SP power its mission profile and operating sequence must be carefully planned to satisfy MEC power requirements while still allowing adequate power allocation to other users. Ideally, any significant extra amount of power, temporarily unused by one SP payload, should be channeled to other payloads that can effectively utilize it.

Table 6-5. Crew Functions in Deployment, Retrieval and Servicing

EXTRAVEHICULAR TASKS	INTRAVEHICULAR TASKS
• DISCONNECT/RECONNECT ORBITER UMBILICAL	• CONTROL RMS MANIPULATION OF MEC FROM AFD
• ATTACH, REMOVE RMS GRAPPLE FIXTURE*	• ATTACH/REMOVE MEC, EOS, MEC PAYLOADS BY REMOTE CONTROL
• MONITOR MEC ATTACHMENT TO S/P	• MONITOR MEC STATUS
• MONITOR EOS ATTACHMENT TO MEC	• VERIFY MEC ATTACHMENT TO S/P AND CHECKOUT SEQUENCE
• MONITOR RESTOWAGE OF MEC IN CARGO BAY (KEEL TRUNNION ALIGNMENT WITH RETENTION FITTING)	• PROVIDE SUPPORT TO EVA CREW MEMBERS
• CONTROL/PERFORM PAYLOAD OR SAMPLE CHANGEOUT	• MAINTAIN CONTACT WITH MCC/POCC DURING ABOVE ACTIVITIES
• ASSIST IN MEC HANDLING CONTINGENCIES (RMS MANIPULATION, SECURING AUXILIARY RADIATORS, ETC.)	• PERFORM CONTINGENCY AND OTHER TASKS IN SUPPORT OF ABOVE AS REQUESTED BY MCC

*Alternative: fixed grapple locations, often less accessible to RMS

Table 6-6 lists mission planning and operating rules that should be implemented for best utilization of Space Platform resources. Time-sharing of available power as previously illustrated in Figure 4-15 may have to be resorted to for some MEC payloads that do not require the entire six-month (minimum) mission duration for completion of their program.

6.7.2 Efficient Management of Payload Mix

Typical MEC missions will carry a mixed payload with short, medium and long processing time requirements. Figure 6-18 schematically illustrates a scenario whereby these different operating time requirements are accommodated in a staggered operation. The operation sequence of five payloads shown in this example also avoids drawing more power at any time than would be required for three payloads.

Other options for accommodating differences in total payload processing times (if power time-sharing is not an issue) would be either to permit some of the payloads to remain idle after completing their processing program or to perform payload changeout on orbit as discussed before. This involves a tradeoff between the value of unused time of payload bay occupancy and the cost of carrying extra payloads or the respective share of servicing costs.

6.8 REMOTE MEC PROCESS CONTROL

6.8.1 Ground-Based Control

The MEC system and its payloads will be designed to operate primarily by programmed automatic sequences supplemented if necessary by monitoring, command and reprogramming instructions from the ground. A maximum degree of automated and autonomous operation will be desirable and reliance on ground-based modes minimized through advanced automation technology and artificial intelligence as these disciplines evolve to greater maturity.

The schematic diagram shown in Figure 6-19 shows the interface of ground-based MEC process control with the space-borne, normally automated system. Replacement of human operator monitoring and remote control functions by fully automated control will depend on the degree to which the system will incorporate machine intelligence and fault-tolerant design techniques.

Table 6-6. Effective SP Resource Utilization by MEC

1. AVOID UNUSED POWER CAPACITY
   - EXPLOIT OUTAGE TIME LEFT BY OTHER USERS
   - TURN ON EXTRA MEC PAYLOADS AT INTERVALS NOT USED BY OTHERS
   - EXPLOIT SEASONAL POWER PEAKS

   ACHIEVABLE BY OPERATING ON LEAN POWER BUDGET

2. STAGGERED TIMING OF MEC USER PEAK LOADS

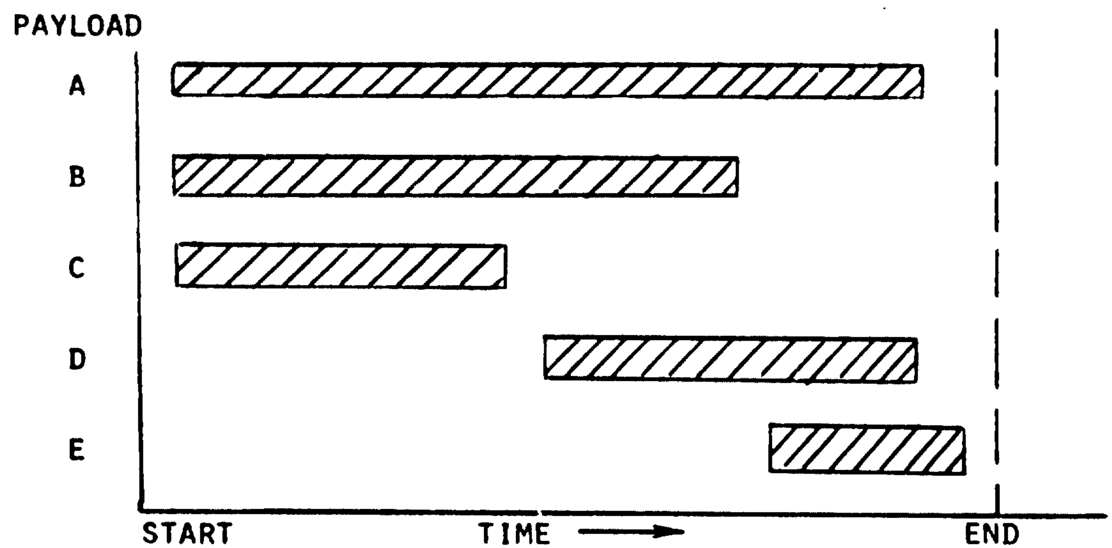
3. REPLACE MEC PAYLOADS THAT FINISH PROCESSING OBJECTIVES EARLY (ON-ORBIT SERVICING)

4. PLAN MISSION FOR OPTIMUM PRODUCTIVITY (PAYLOAD MATCHING)

5. COORDINATE UNAVOIDABLE MICRO-G DISTURBANCES (REBOOST) FOR NON-INTERFERENCE WITH LONG-DURATION MEC PROCESSES

6. COORDINATE TDRSS ACCESS TIME FOR JOINT USE BY MEC, OTHER PAYLOADS

7. COORDINATE SERVICING EVENTS BETWEEN MEC, OTHER USERS



- TYPICAL MIXED PAYLOADS WILL INCLUDE LONG, MEDIUM AND SHORT DURATION EXPERIMENTS

- ACCOMMODATION OPTIONS

  1. PERMIT IDLE TIME ON ORBIT
  2. CARRY ALTERNATE P/L'S ON MEC THAT WILL UTILIZE "IDLE" KW-HOURS
  3. PERFORM ON-ORBIT PAYLOAD CHANGEOUT

- TRADEOFF BETWEEN COST PER IDLE TIME, COST OF SPARE P/L

Figure 6-18. Managing Payload Mix

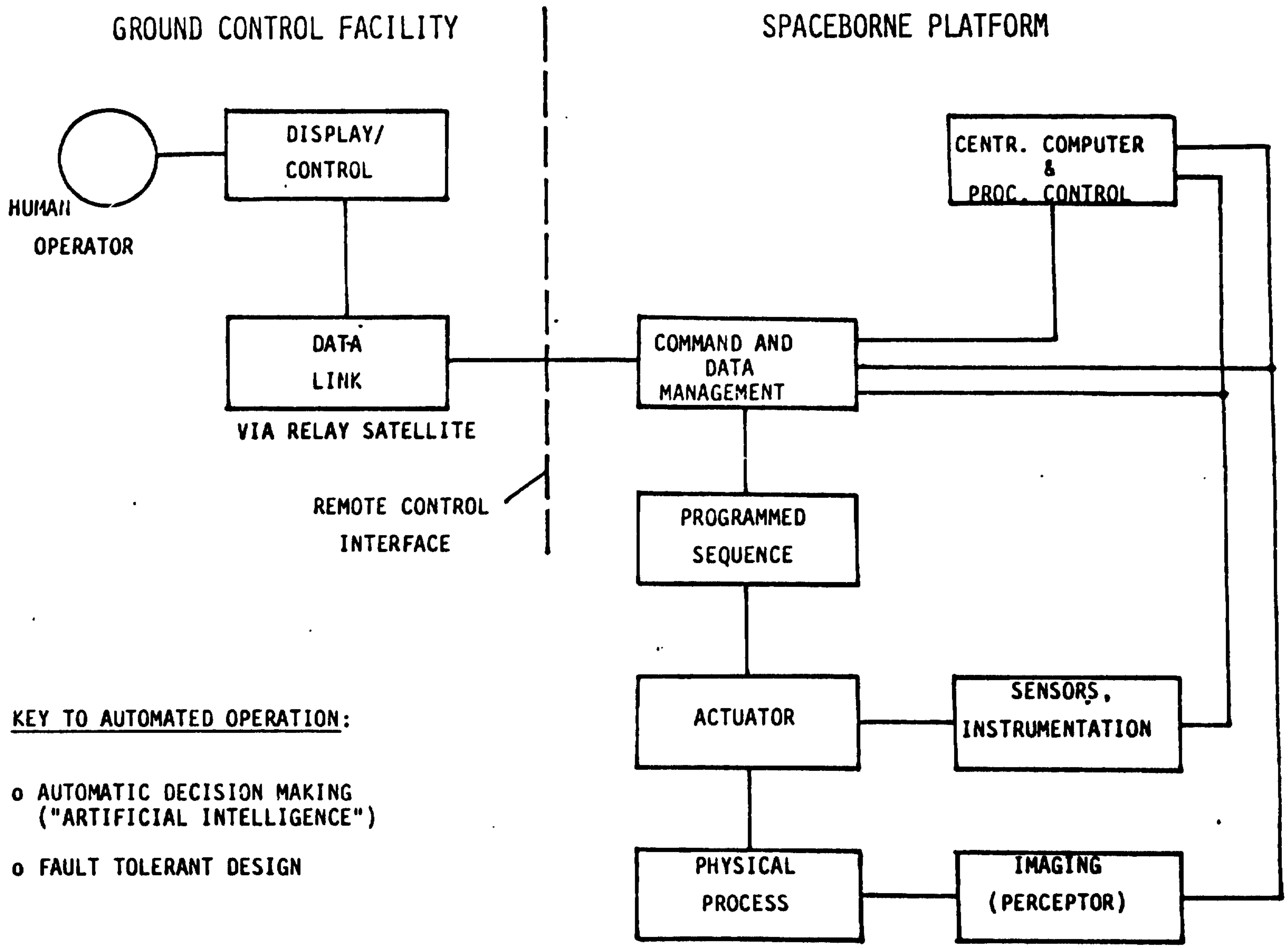


Figure 6-19. Schematic of MPS Remote Control and Automated Operation

Even with the anticipated increase in automated operations, however, interactive ground-based control modes of critical MEC processes must be provided, including telemetry of image data (in all-up MEC) to ground control personnel at the MEC Payload Operations Control Center (POCC). The remote control loop includes MEC and SP data handling, command and communication subsystems, SP-to-ground communication links via the TDRSS and the POCC.

6.8.2 Shuttle-Based Remote Control

Shuttle flights not otherwise related to MEC missions offer opportunties for remote MEC process control through extended periods of direct radio contact. Such contact periods occur regularly in coplanar as well as non-coplanar orbits and may extend over many hours, depending on orbital geometry. This remote MEC process control mode may be utilized as an alternative or backup to ground based real time process control if normal POCC/TDRSS communication channels do not provide sufficient time for remote control access to MEC. As an example, the mode will be useful in contingencies where automatic failure detection and diagnostics onboard the MEC must be augmented by the human operator. (See also Reference 6).

6.8.3 MEC Process Operation and Fault Correction

Table 6-7 presents a summary of autonomous and automatically sequenced process operations performed by each MEC payload, and lists functions involved in fault detection and fault correction. Some of these require computer-controlled switching of redundant elements using conventional fault detection/correction techniques. These operations will be performed automatically by the MEC central computer, aided by ground-based commands if necessary.

Autonomous fault correction features will have to be developed as a part of MEC technology evolution. This evolution should utlimately lead to the capability of automatically detecting and correcting not only equipment failures, but also processing faults or degradation. The latter will initially need remote monitoring by ground control.

Table 6-7. MEC Process Operation and Fault Correction

ROUTINE PROCESS OPERATIONS

- PROGRAMMED EVENT SEQUENCES, REPEATED OVER AND OVER
- SAMPLE HANDLING BY "ADDRESS" CODE, PART OF SEQUENCE
- BATCH PROCESSES, ALTERNATING WITH PARAMETER CHANGES, WITHIN SEQUENCER SCOPE
- PERFORMED AUTONOMOUSLY EXCEPT FOR COMMAND OVERRIDE SITUATIONS

FAULT DETECTION/CORRECTION

- FAULT DETECTION ESSENTIAL. REQUIRES SOPHISTICATED INSTRUMENTATION
- AUTOMATIC FAULT CORRECTION BY REDUNDANT ELEMENT SWITCHING, REQUIRES STEPPED UP SOPHISTICATION OF CONTROL LOGIC
- SYSTEM PROVIDES AUTOMATIC TURN-OFF CAPABILITY FOR PROTECTION
- DISTINCTION BETWEEN SYSTEM FAULTS AND PROCESSING FAULTS/DEGRADATION: QUESTION HOW TO REPLACE HUMAN OPERATOR PERCEPTION OF PROCESS FAULTS
- LAST RESORT: REAL TIME GROUND CONTROL INVOLVEMENT, USING VIDEO MONITORING
- FULLY ROBOTIC OPERATION WILL EVOLVE GRADUALLY, NOT IN EARLY OR EVEN ALL-UP MEC

6.9 SAFETY

The MEC mission in all of its phases inherently presents hazards which may cause damage or injury to equipment and personnel including:

- Ground facilities and/or crews
- Shuttle Orbiter and/or crew
- Shuttle payloads other than MEC
- Space Platform
- SP payloads other than MEC

Such hazards must be reduced to a minimum/acceptable level by strict adherence to safety policies and guidelines in equipment design and handling procedures, by eliminating hazardous operating conditions, and by careful attention to environmental hazards the system may be exposed to. This should be emphasized even in the earliest concept definition phase of the program. NASA safety requirements and guidelines (References 11, 20) were reviewed during this study and all efforts made to define MEC design and mission concepts compatible with these requirements.

Examples of potential hazard sources and hazardous operations in the MEC mission include the following:

1. Ground handling during MEC integration and checkout, Shuttle installation, post-flight removal, transportation and refurbishment.
2. Shuttle transportation to and from orbit.
3. Shuttle on orbit operations involving MEC handling during deployment, servicing and retrieval phases.
4. Handling by the TMS.
5. MEC operations as SP payload, in the free-flying mission phase, during departure from, and rendezvous/docking with the Orbiter.

Examples of damage potential inherent in MEC equipment and mission operations, including those of interfacing system elements, are the following:

- Explosion and fire
- Excessive temperatures (internally and on surface)
- Electric shock, short circuits
- Spillage of fluids (coolant, payload contents)
- Collision
- Failure to demate (from SP) or retract deployed structures

Of particular concern are hazards in transitional mission phases with damage/injury potential to the Orbiter and crew, such as berthing, RMS manipulation, crew manipulation, EVA operations near or inside MEC enclosures during service, mechanical jamming in mating/demating, and others.

Ways to avoid or minimize these hazards were incorporated into the MEC conceptual design and mission definition. It should be noted, however, that hazard analysis and hazard reduction will not be the responsibility of the MEC program alone, but also involves the SP mission and operating modes and Orbiter/crew activities such as SP retrieval, rendezvous, berthing and payload manipulation by the RMS.

The MEC program must take responsibility for potential hazards introduced by prospective MEC payloads. All of these must be analyzed, managed, and certified for safety by the MEC Safety Review Board so as to assure strict implementation of safety policies and procedures by each responsible payload organization. It is recommended that these issues be addressed in greater depth in future MEC design studies.

6.10 END-TO-END MISSION ASSESSMENT

The MEC design and mission concept is keyed to flexible and effective utilization of the Space Platform and its resources as well as Shuttle launch capacity utilization. Its mission profile imposes few if any constraints on other users of the SP and the Shuttle. Support requirements placed on ground handling operations prior to launch and after return from orbit and on payload operation control are mostly routine.

The principal area of concern is MEC competition with other users for available SP power, especially in the era of a limited (12.5 kW) capacity, early SP. This concern can be alleviated to some extent by careful premission planning and strict priority allocation via mission profile protocol for all users sharing the Space Platform. Compromises will be worked out by requiring time-shared operation.

MEC design and operation planning is amenable to time-shared use of available power, by carrying extra payloads that would remain in standby, awaiting their turn of SP power allocation. In this manner the 6-month minimum mission duration (twice as long as originally envisioned

in the MEC Study, Part 1) can be turned to advantage in trading allocated power level against the extra flight time.

On-orbit servicing, especially the ability to accommodate both basically short-duration and long-duration process payloads on the same flight, is a principal ingredient in raising payload productivity, operational flexibility and SP companion payload accommodation compatibility.

Figure 6-20 gives an overview of relevant factors in end-to-end assessment of MEC mission characteristics, with emphasis on interrelations of MEC with all other participating elements involved in and/or supporting the mission. These factors are listed next to the various participants that interface directly or indirectly with MEC in mission operations. Entries with solid bullets are those characteristics that rate high marks in the mission effectiveness assessment. Open bullets indicate areas of some concern in terms of the level of support requirements demanded by MEC, constraints imposed by MEC or areas of potentially conflicting requirements between MEC and other users. None of these, however, are of the kind that could not be resolved by appropriate mission planning or an increase in allocated resources.

Figure 6-21 presents a corresponding assessment of MEC performance in successive mission phases.

Table 6-8 is an overall mission assessment chart, comparable to the configuration assessment shown in Table 4-12. Using three rating levels, 1-satisfactory, 2-good and 3-excellent, this chart shows that initial MEC missions, despite their limited performance range, still rate high in cost effectiveness and utilization of resources available on the early 12.5 kW Space Platform. All-up MEC missions provide the expected performance improvement on most counts, especially in terms of mission flexibility, through servicing, and overall payload accommodation, owing to longer mission durations and greater SP power level.

A point of interest is the potential continued usefulness of the initial MEC if kept in the inventory as a second MPS payload carrier. This would permit flying limited-duration missions with low power requirements at times when (1) other types of Space Platform payloads would have priority of SP resource allocation, (2) Shuttle capacity would not be able to accommodate an all-up MEC or (3) for some reason of payload logistics the full capacity of an all-up MEC could not be utilized. The latter condition might occur if a 6-month MEC turnaround time between SP revisits by

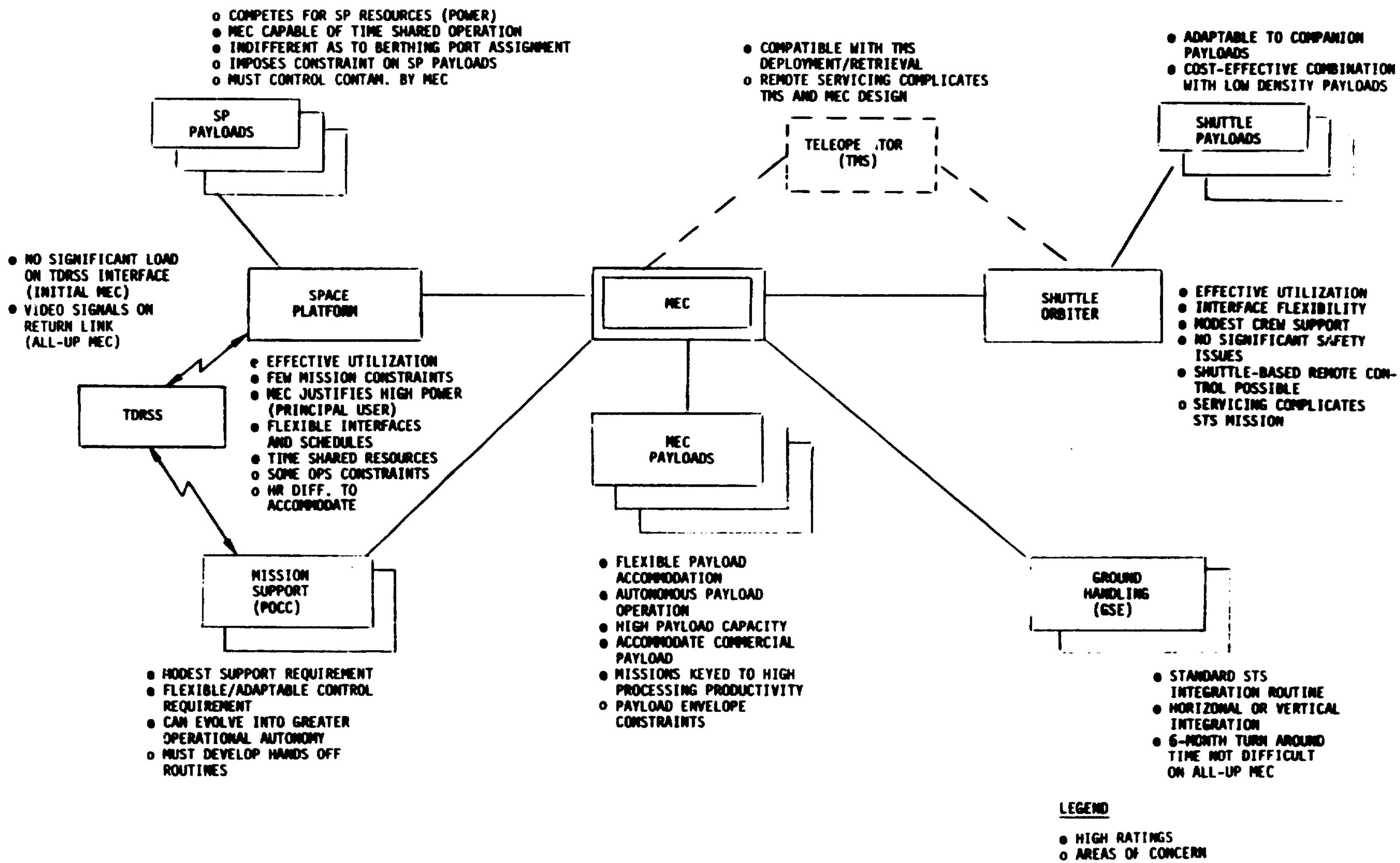


Figure 6-20. Key Factors in MEC Mission End-To-End Assessment (Interactions)

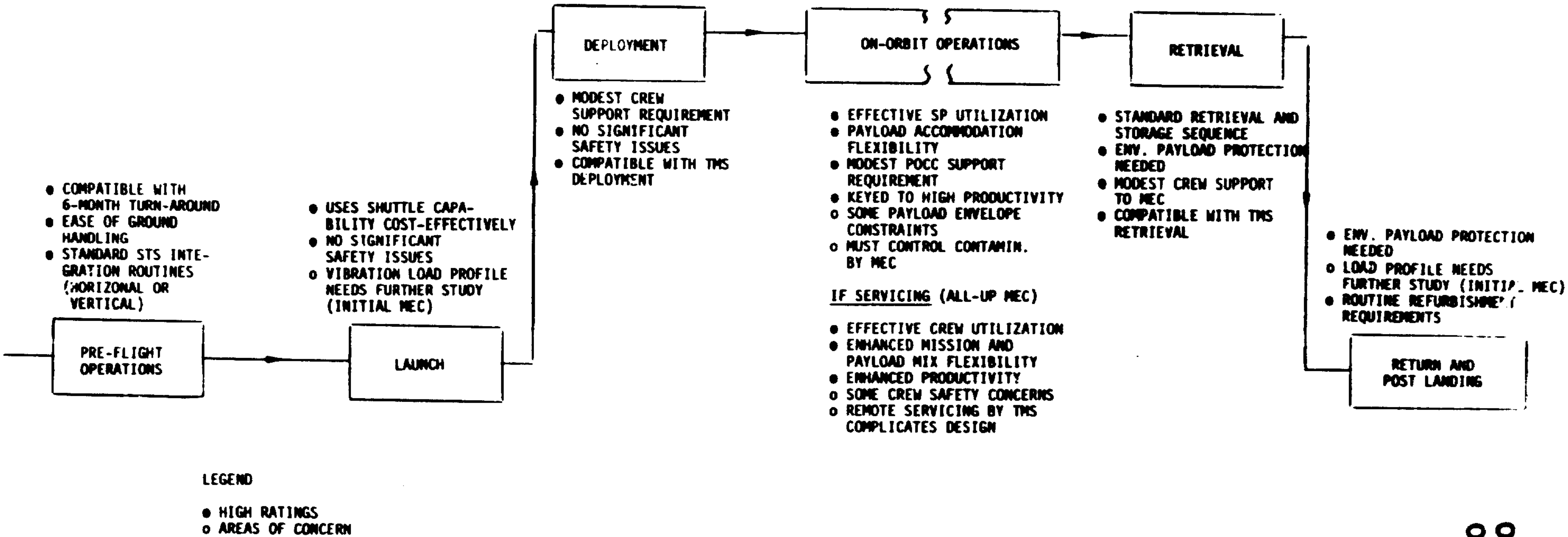


Figure 6-21. MEC Mission End-To-End Assessment (By Mission Phases)

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Table 6-8. End-to-End Assessment of MEC Mission

CHARACTERISTICS/CRITERIA	RATING: INITIAL MEC 1	INITIAL MEC 2	INITIAL MEC 3	ALL-UP MEC 1	ALL-UP MEC 2	ALL-UP MEC 3	COMMENTS
1. Payload Accommodation							
- Resource Capacity		●				●	
- Flexibility/Versatility		●				●	
- Growth Capability			●			●	
- Autonomy			●			●	
- Payload Mix (long/short missions)		●(1)				●	(1) Fixed 6-month missions
- Commercial Payloads and Quick Look, Unconventional Payloads	●(2)					●	(2) Size and accommodation constraints inherent in concept
2. Shuttle Utilization							
- Length/Weight Economy			●		●		
- Compatibility With Launch Schedule			●		●(3)		(3) 6-month turn-around is tight
- Ease of Accommodation (other P/L's)			●		●(4)		(4) All-up MEC rides in mid/aft bay
- Crew Capability Utilization		●(5)				●	(5) No servicing on orbit
- Safety			●			●	
3. Space Platform Utilization							
- Resources Exploited			●			●	
- Flexibility of Requirements		●(6)				●	(6) Uses 80% of available power
- Ease of Accommodation (other users)		●				●	
4. Other							
- Ease of Servicing On-Orbit		N/A			●(7)		(7) Configuration-constrained
- Ease of GSE Support			●		●(8)		(8) Tight turn-around schedule
- Ease of POCC Support			●			●	
- Ease of TDRSS Support via SP			●		●(9)		(9) Imaging data exceed SMA channel capacity
- Evolution Potential			●			●	

RATINGS 1-Satisfactory 2- Good 3-Excellent

the Shuttle would be insufficient for refurbishment and payload integration of the all-up MEC but adequate for the initial MEC.

7.0 TECHNOLOGY REQUIREMENTS

The selected MEC concept, including both the initial and the all-up MEC systems, can be developed, built, and operated through use of established space technology. No major advances in spacecraft and subsystems hardware are required to accomplish early MEC missions.

7.1 TECHNOLOGY GROWTH

Inheritance of flight proven technology based on Shuttle and Spacelab MPS hardware, software and operational procedures, will aid in the evolution of the MEC program. Even in early Spacelab MPS missions some payloads such as the Solidification Experiment System (SES) will function largely as automated units with little or no human operator control intervention. Future automated MPS experiments also are expected to be developed via initial Shuttle/Spacelab mission exposure before they will be converted to free-flying operations for extended durations. New departures in most of the technical disciplines of power control, thermal control, data management, instrumentation and mechanism design that are peculiar to materials processing will thus be avoided.

The evolving MEC program has several intriguing areas that will profit through development of advanced systems and/or components from related projects that parallel MEC. The entire NASA low Earth orbit platform program includes the Power System, Science and Applications Space Platform, Teleoperator Maneuvering System, and MEC. Concurrent development of these platforms should allow for advanced technology development to flow to each. Examples are:

1) Rotating mechanical joints that allow leak free fluid flow across the interface. Also thermal control pumps, heat exchangers and radiators.
2) Quick disconnect hardware that allow ease of access to replaceable/serviceable equipment.
3) Standard docking/berthing adapter devices.
4) Lighweight electrical power system combined with the requirements for autonomous operations, high voltage, high power, survivability/environmental effects for long life missions.

Like the MEC project itself, the associated technology needs will expand as the project evolves from initial to all-up versions. The

initial MEC 1987 flight will require no new technology based on the assumptions that is will accommodate three highly autonomous payloads on missions with a preprogrammed protocol of payload operations and no on-orbit servicing. In the long term, an all-up MEC system is envisioned that contains sophisticated automation/intelligence functions built into the command/data management subsystem (CDMS), as an evolutionary growth to match the evolutionary progress of the MEC vehicle and its advanced payloads. The advanced CDMS would be capable of optimizing the mission product despite payload operational sequence changes, MEC mission contingencies, and anomalous events.

7.2 SPECIAL PROJECTS

While no new technological development needs have been identified to implement the MEC project with an initial capability for 1986 flight, the following three areas are recommended for technology study to aid in the successful evolutionary growth from the initial to the all-up MEC configuration.

7.2.1 Narrowband TV or Imaging Systems for Ground Based Experiment/Payload Control

This requirement originates with certain crystal growing processes that, in the laboratory, require manual control by a skilled technician during critical phases. In this same discipline, certain anomalies in the crystal growth can be detected visually and the process corrected or terminated if necessary. Although full commercial TV discrimination range and time response would be desirable for performing these tasks remotely, the difficulty and cost of providing such a system, on demand, in real-time, makes it necessary to re-evaluate the imaging requirements.

The minimum mandatory information content of the image should be established for each process and process phase that must have remote manual assistance. It is expected that, in most cases, adequate information can be made available within a reasonable telemetry band. When this is the case, a multiplexing technique can be developed that is well within the state-of-the-art of communication technology.

The advanced technology required here is concerned with finding a best mix between automation and manual assistance for particular processes. Both analytical and experimental techniques appear to be needed.

7.2.2 Automated Materials Sample Handling and Storage Apparatus

Automation in this context can be used for two different purposes. In one case, it could contribute to reducing the size, and probably weight, of the sample handling and storage system. This becomes important with MEC because of the large number of samples that is contemplated and because there will be a variety of preferred sizes among the samples. Present sample handling schemes use indexed positions for each sample and a simple mechanism goes to a particular position and moves that sample from the designated spot to the processor and returns it. The minimum size sample system would accrue by having the samples stored together in a relationship that does minimize storage volume for that set of samples. Another flight set of samples would have a different relationship and system size. This method requires, however, an adaptable transport mechanism, which involves flexible position indexing and gripping, handling and transporting of samples. New technology for this case requires modeling of the search and recognition function, development of special sensors (visual or tactile) and development of flexible gripping and transporting mechanisms.

The other case involves provision for possible failures in the storage and transfer system. As this system is largely mechanical, the provision of redundancy in major parts is impractical. Achieving reliability in the presence of such single point failure modes is not a new technology. Rather, conservative design and extensive testing have been used successfully in most space projects. The nature of many MPS experiment samples, however, precludes assuring their failure free movements to the processor and return through use of these techniques. Some failure modes could jam the entire sample movement mechanism, make a processor unavailable, or temporarily block sample transport and so waste a processor cycle.

New technology for this case should start with a failure mode and effects analysis of candidate sample movement and storage systems using the best understanding available on necessary system configurations. The next step would be development of sensing systems for detection of higher probability failure modes and provision for appropriate responses in the handling system.

7.2.3 Adaptive, Intelligent Avionics Systems

Within specific materials processors, there exist a number of opportunities to optimize scientific return through use of machine intelligence (computer control and robotics). Relieving dependence on the "man-in-the-loop" as discussed in Section 6.8 as an example could also lead to major cost savings.

Using machine intelligence in the MEC to optimize the overall payloads and subsystems operations in complex because of the number of levels in the decision hierarcy.

The objective of this development would be to enhance the process going on within the payload to: increase the productivity of all the MEC payloads on a given flight, reduce the cost of MEC missions by elimination of excessive telemetry/stored image data, and lower MEC mission cost by reducing the amount of manpower/equipment for ground control.

We know that NASA is very interested in the automation of materials processing (both ground and space). They are convinced that in the long term, extra-terrestrial materials will have to be used in the performance of some future space missions. Use of these materials will require development of highly automated processing systems. Ideally, if replication technology could be perfected to the point that systems with self-replication capability are developed, an extra-terrestrial base could be established. The MEC project seems like a good place to start this work. This base could grow with time.

On the all-up MEC, which was the concept we concentrated on in the study Part 1, we have the challenge to perform successful materials processing on long duration, multi-payload, multi-discipline, multi-mode missions. Dynamic behavior of complex MEC subsystems must be accounted for and controlled by "smart" sensors and mechanisms, operating remotely and automatically.

This technology development must counter the philosophy of . . . "Fix hardware malfunctions with software patches, fix software problems with operational procedures."

Use of intelligence in the initial MEC avionics system will most likely be for countering contingencies and anomalous operation within the

MEC systems and to prevent problems within payloads from endangering the SP or its other payloads.

As long as detailed process control is kept in the payloads, near term needs for new technology in the MEC avionics systems are minimized. These systems should, however, make use of the most up-to-date fault tolerant designs that are appropriate to the MEC mission duration and maintenance modes.

8.0 RECOMMENDED AREAS OF FUTURE STUDY

The following work is suggested to provide a more solid basis for starting the MEC Phase B study.

8.1 MEC DESIGN

Selection and further definition of the selected preferred MEC concept depends on concurrent development of MEC payload designs and operating profiles. In this MEC design study, a standard payload envelope and interface concept was adopted which allows flexibility in payload accommodation and convenient access for payload integration and interchange on the ground and payload servicing on orbit.

For similar reasons, the initial and all-up MEC design concepts emphasized payload autonomy rather than centralized MEC payload support functions. Confirmation of this design approach, and its assessment as the most cost effective path to system development/integration, is required as payload design activities progress and additional data on payload operations and interface requirements become available.

8.2 MEC PAYLOADS

Development of automated MPS payloads to be flown on MEC will be a gradual, evolutionary process. Prior flight experience of Materials Experiment Assembly (MEA) packages and of Spacelab MPS payloads will be available on most processes to be included in subsequent MEC missions. Four to six experiment packages/payloads currently in advanced development fall into this class. Others still require extensive definition, breadboarding and development.

The impact of projected payload characteristics and requirements on MEC design and operations must be taken into account on a timely basis. The concept of "standardized" MEC payload accommodation provisions that were adopted, largely to fill a gap in current knowledge of specific payload design requirements, should be affirmed or modified as necessary, at the earliest time, to avoid a MEC development that would unnecessarily restrict the growth of MPS payload support capabilities or require substantial future MEC design changes.

8.3 AUTOMATION

Transition from ground-based laboratory processes and Shuttle-based MPS experiments to fully automated payload operations constitutes the single, most challenging technology advance involved in bringing about a successful, practical, reliable and cost-effective MEC program. Evolution to fully automated operations without heavy ground-based monitoring and intervention will be required as the growth of MPS/MEC activities progresses from initial R&D missions to full commercial exploitation. Further study and breadboarding is suggested. Increased reliance on machine intelligence, which will minimize cumbersome and costly ground facility/human operator intervention and control, is expected to take place as the results of NASA's current thrust in developing this technology. In this respect, MEC will provide an effective and convenient transition path, with less than critical dependence on fully automated payload operations, until this new technology is matured.

8.4 ON-ORBIT SERVICING

The other facet of an orderly transition to fully automated payload operations on MEC is provided by planned, periodic on-orbit servicing operations being part of the MEC mission scenario. This will provide the opportunity for replacement or repair, if necessary, of payload units that fail to perform satisfactorily in the fully automated processing mode. The capability of early hands-on correction of such malfunctions on-orbit will reduce the risk inherent in committing sophisticated new payload equipment to extended missions in the early stages of the MEC program. The MEC project will benefit by additional study in this area.

On-orbit servicing, like other MEC mission phases requiring repeated Orbiter/Power System rendezvous and docking, will involve intricate, crew supported Orbiter operations that will only gradually evolve into routine activities. This aspect of the MEC mission does not require novel technology, per se, but involves a build-up of experience by Shuttle flight and ground crews. Principal concerns, regarding MEC design and mission planning, are an awareness of the inherent complexity of these orbital operations, a practical design approach that emphasizes simplicity and reliability, especially in interface implementation, and systematic elimination of safety risks involved in MEC/payload manipulation by Shuttle crewman.

APPENDIX A

EXPLORATORY INITIAL-MEC DESIGNS

Exploratory initial-MEC design concepts investigated during the study are presented in this Appendix. They include the following configuration types.

1) Pallet-based configurations including the full pallet, half pallet and combinations of pallet and other payload support structures.
2) MEA-C based configurations involving only minor changes from the MSFC spoked-disc design.
3) MEA-C based configurations involving major modifications from the support disc design.

Table A-1 lists principal features of the eleven concepts studied and indicates payload accommodation capabilities. Additional design aspects are summarized in Section 4.2, Table 4-2.

Each of the design drawings shown below is accompanied by a brief description and assessment of its characteristics. It should be noted that the selected configuration (Concept M) discussed in Section 4.4 based on the Advanced MEA spoked disc also includes characteristics that evolved from this exploratory design study.

A.1 CONCEPT A_1 (DRAWING MEC2-01)

The drawing shows MEC and EOS attached to the Space Platform. Four berthing ports are depicted as well as the deployed SP radiator (vertical surface). The prism phantomed in the lower right-hand corner represents the berthing SP arm envelope. MEC consists of a standard ESA pallet fitted with a berthing mechanism on the underside to engage the SP +z port. SES is shown as an envelope block, attached to the pallet at the base. MEA consists of seven canisters (30 in. dia. x 45 in. long), a support beam, assembly struts to pallet hard points and subsystem equipment (not shown).

Access to the canisters is excellent as is the top access to SES. Forward side access to SES may be impaired by the deployed SP radiator. Retraction of the radiator would improve access but may not be desirable for operational reasons.

Table A-1. Features of Exploratory MEC Designs Shown in Drawings

DESIGN CONCEPT	DRAWING NUMBER	STRUCTURE TYPE			PAYLOADS ACCOMMODATED			REMARKS
		PALLET	SPOKED DISC					
			MINOR MOD.	MAJOR MOD.	SES	MEA	EOS	
A_1	MEC 02-01	●			1	7	-	EOS Attached Separately
B_1	MEC 02-02	● (1½)			2	7	●	
C_1	MEC 02-03		●		2	7	●	
D_1	MEC 02-04	● (1½)			1	7	●	
-	MEC 02-05				(1)*	(7)	(●)	Modular Structure**
-	MEC 02-06	● ½			-	7	(●)	
E_1	MEC 02-07		●		-	7	●	
-	MEC 02-08				1	7	(●)	Modular Structure**
-	MEC 02-09				2	-	-	New Structure, Coupled to Other P/L Carriers
F_1	MEC 02-10			●	1	7	●	
-	MEC 02-11			●	1	7	(●)	
G_1	MEC 02-12		●		2	7	●	
H_1	MEC 02-13	●			1	8	●	Pallet With Superstructure
J_1	MEC 02-14 MEC 02-17				1	6	●	
K_1	MEC 02-15 MEC 02-16			●	1	8	●	MEC Growth Module Shown Attached
L_1	MEC 02-18			●	1	8	●	

*Payloads in ( ) can be accommodated, but not shown in drawing
**Based on MBB SPAS bridge structure

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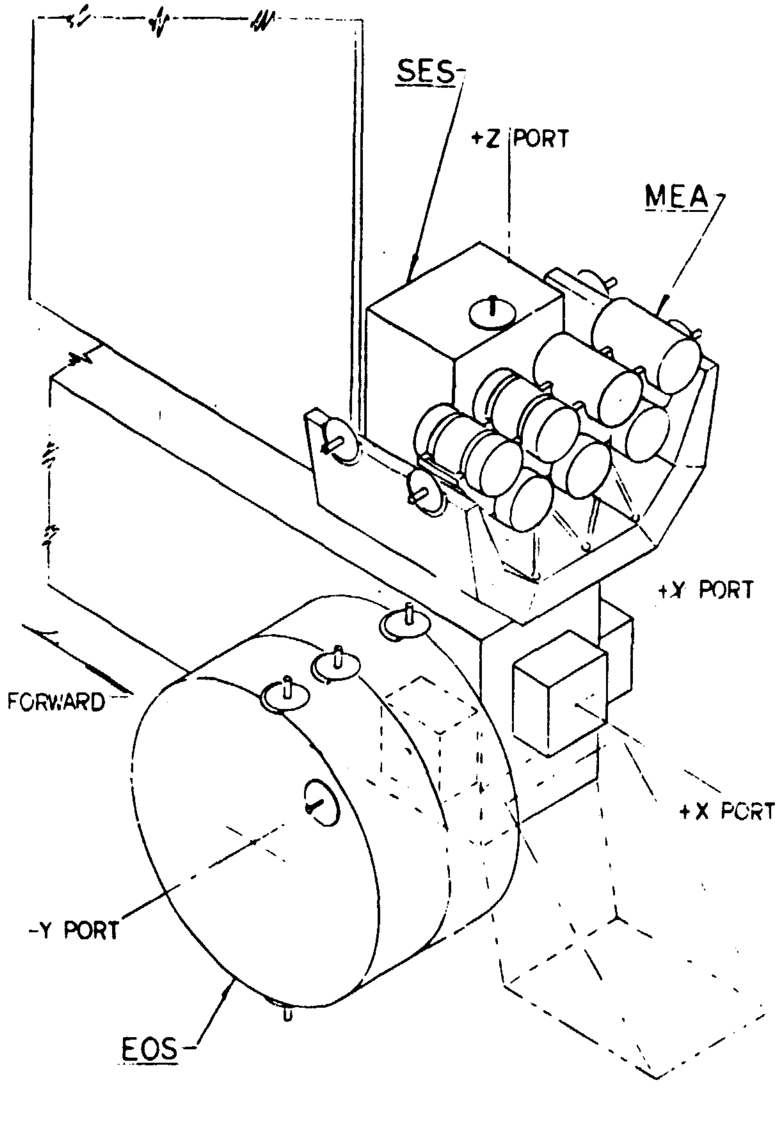

Figure A-1. Concept A_1 (Drawing MEC2-01)

Available data on EOS shows no berthing provisions. It was assumed that a berthing device is attached to the Factory Module. Space Platform berthing of the EOS is shown at the -y port. The outboard half of EOS, the Resupply Module, is accessible for changeout. In this concept, EOS is treated as a separate payload, disassociated from MEC. This "two package" approach offers minimal development expense.

A.2 CONCEPT B_1 (DRAWING MEC2-02)

The Space Platform representation for this concept is the same as for Concept A_1. An additional item of SP equipment to be cleared is the trunnion structure envelope shown as a phantom box at the aft base of the radiator. MEC consists of an ESA pallet, a half-pallet and the EOS system, rigidly joined to constitute a single unit. The stack height of this arrangement is approximately 24 feet above the +z port. End mounting of the ESA pallet requires that a berthing adapter be designed and integrated into the pallet structure. This adds approximately 20 inches to the length of the pallet. Two SES units, base mounted, absorb the length capacity of the pallet.

The MEA, configured in the from of a "wine rack", is the same as that shown on Drawing MEC2-01 but occupies the half pallet rather than sharing a full ESA pallet with SES. By attaching the EOS Factory Module to the MEA half pallet, a berthing adapter on EOS is avoided. No on-orbit access to the MEA canisters and only limited access to SES units is provided making this concept suitable only for missions where orbital servicing is not required. Occupancy of a single SP port by all MEC payloads is a favorable feature, providing that the resulting SP mass distribution is acceptable.

A.3 CONCEPT C_1 (DRAWING MEC2-03)

This concept is a departure from the previous ESA pallet configuration, justified on the basis that a custom-designed structure may accommodate MEC payloads more efficiently than a "standard" all-purpose structure. A trade of structure development cost vs. payload accommodation efficiency is a principal issue.

The custom designed structure in this concept fits two SES units back-to-back with their service faces exposed for access. A berthing adapter (male) is mounted on the botton and another (female) clears the top of the SES units.

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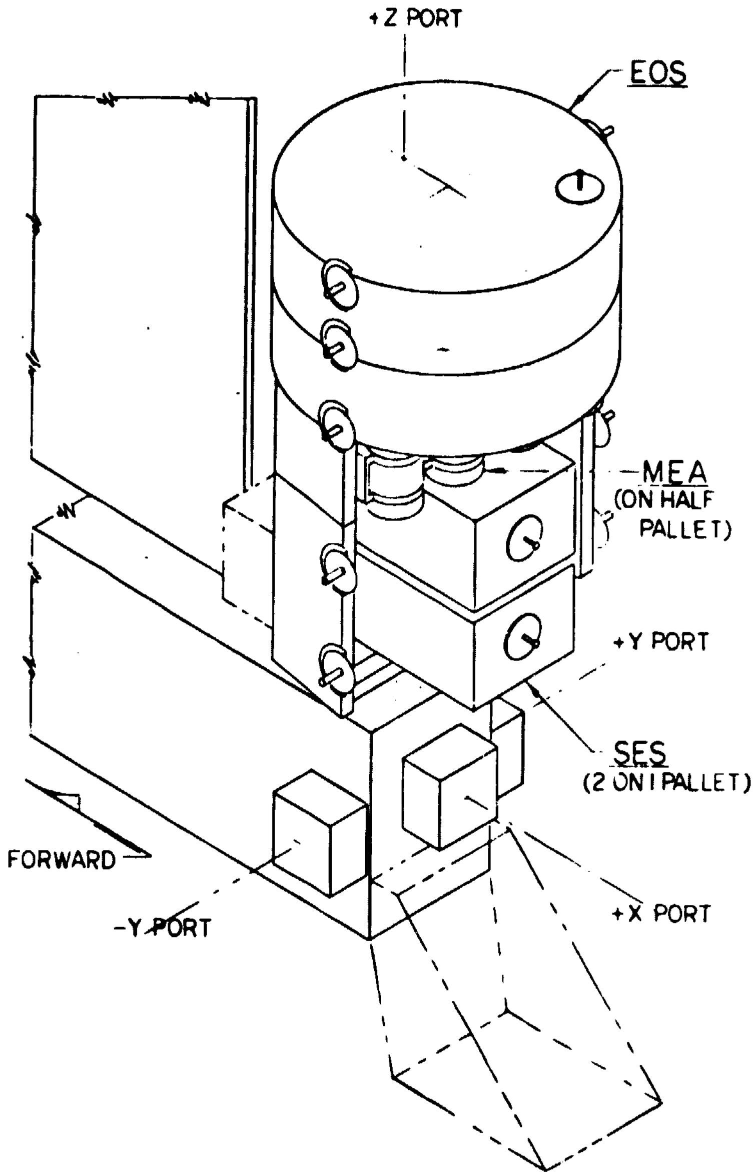

Figure A-2. Concept B_1 (Drawing MEC2-02)

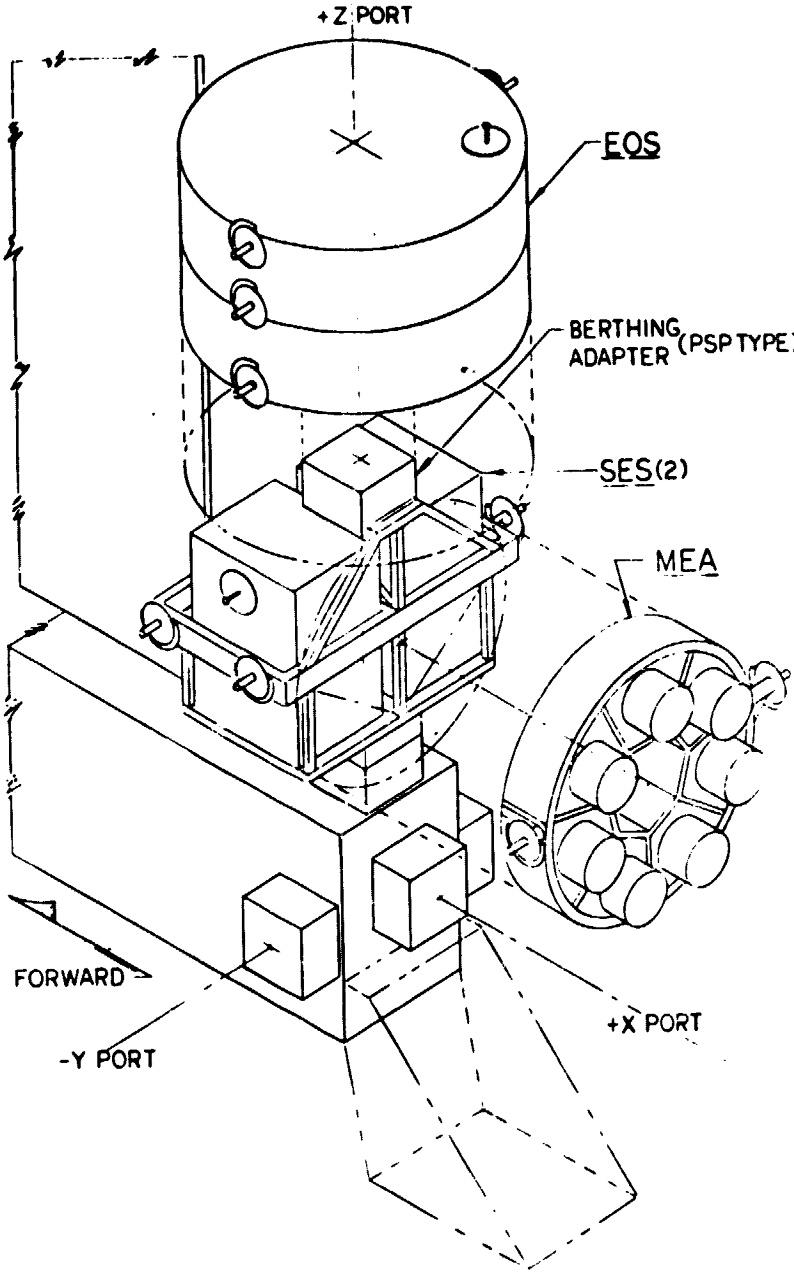

Figure A-3. Concept C_1 (Drawing MEC2-03)

The MEA "Spoked-Disc" arrangement shown was developed at MSFC (see Advanced MEA Study Report, dated March, 1981). The drawing shows a reduced disc diameter (140 inches rather than 168 inches) version while maintaining the same hub size and accommodating 30-inch diameter by 34-inch long payload canisters in the peripheral compartments. Access to the exposed canister ends is excellent. Attachment of the MEA disc to the SES support structure is fixed, producing an integrated MEC using 136 inches of Orbiter bay length. This is 22 inches longer than an ESA pallet but can carry two SES units and a complete MEA system.

EOS uses the berthing adapter atop the SES structure. Feedthrough space between the SES units is provided to handle subsystem lines and cables. This configuration occupies a single SP berthing port.

A.4 CONCEPT D_1 (DRAWING MEC2-04)

A compact arrangement of SES and MEA payloads is shown on a standard half pallet. The arched bridge structure supports seven MEA canisters in a "hair curler" fashion rather than in a straight bridge or "wine rack" arrangement (Concept A_1). The SES envelope has been modified to take advantage of the domed cover in the current SES design.

Permanent attachment of the EOS Factory Module to the half pallet structure avoids on-orbit separation or joining of these structural elements. A berthing adapter is envisioned at the pallet bottom. The orientation parallel to the y-axis on SP is consistent with clearance of payloads on other SP ports. The length of this MEC is 13 ft.

Good access is provided for the MEA canisters, and the SES service side is fully exposed. Greater access to SES is possible if drawer-type sliding tracks are planned for the SES base/half pallet interface. The EOS Resupply Module is accessible for changeout as required. Subsystem lines and cables are relatively short for all three payload categories, because of the central location of the MEC/SP interface.

Development costs for this concept would be slightly greater than those for Concept A_1 which are expected to be minimal.

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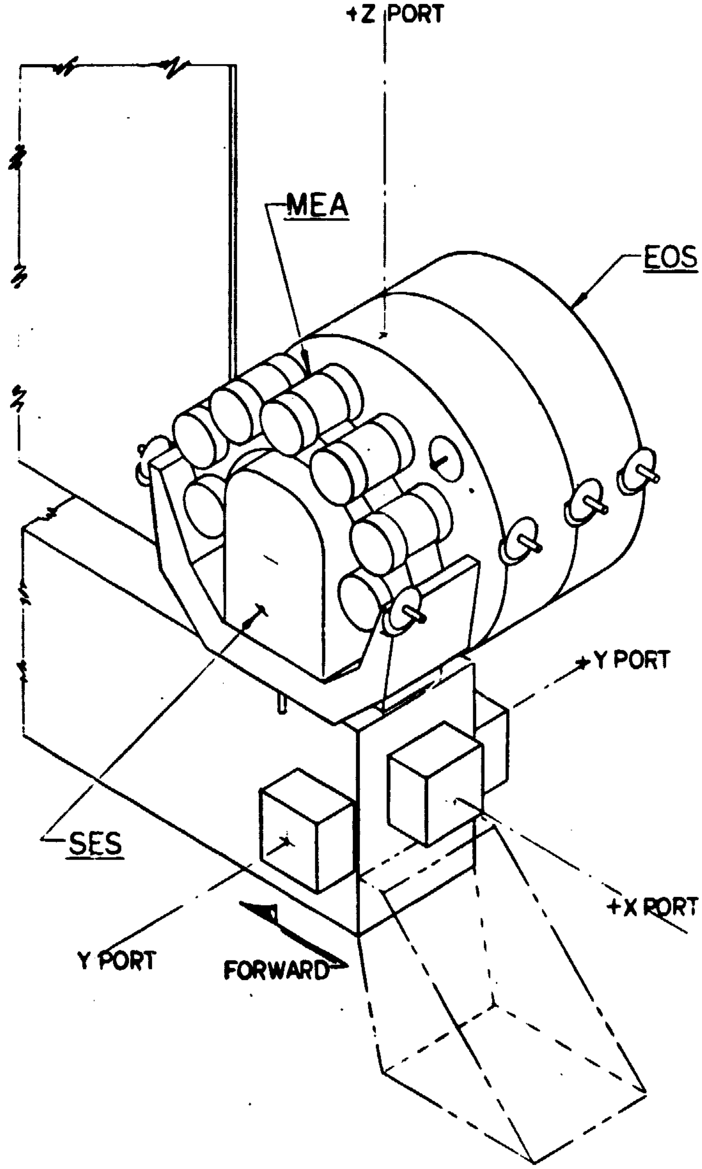

Figure A-4. Concept D_1 (Drawing MEC2-04)

A.5 MEA PAYLOAD CANISTER ARRANGEMENT ALTERNATIVES FOR MEC

A preliminary requirement was established for the MEA contingent of MEC payloads. These are seven cylindrical canisters, each 30 inches in diameter and 45 inches long weighing about 400 pounds. It is assumed that at least one end of each canister will be openable for access to its contents. Blockage of access by the support structure should be avoided.

Three different canister arrangements were shown in preceding drawings: MEC2-01 ("wine-rack"), MEC2-03 ("spoked disc") and MEC2-04 ("hair curler"). A fourth alternative is shown in the sketch number MEC2-06. A half pallet is illustrated as the dedicated structure for this "pantry shelf" arrangement. It is recommended that this alternative be substituted for the "wine rack" type shown on drawing #MEC2-02, Concept B_1, since it permits access to the ends of all seven canisters even though the MEA is sandwiched between SES and EOS payloads. The simplicity of this structure implies inexpensive development.

A.6 MEC ON MODULAR STRUCTURE (SKETCH MEC2-08)

Shown here is an example of the MBB Modular Structure (also see Sketch MEC2-05) configured to carry two MEC payload types. This three-bay structure has a length of 7.9 ft. It is shorter than a full pallet (9.43 feet), but longer than a half pallet (approximately 5 feet). A drop beam structure is used to gain height for payload mounting above the principal horizontal platform. Equipment support plates are not required on the fore and aft vertical faces of the truss structure for this application.

The open truss structure facilitates installation of subsystems. Good access to SES and MEA payloads is provided when berthed to the SP and also when carried by the Orbiter.

This MEC may be converted to carry MEA payloads only by removing one of the bays of the truss structure. Also, a simple expansion is possible by attaching additional structural components to the existing trusses at a moderate extra cost.

A.7 CONCEPT E_1 (DRAWING MEC2-07)

This concept is similar to Concept D_1 (see paragraph A4) but uses a spoked disc instead of a half-pallet to carry MEA payloads and to support

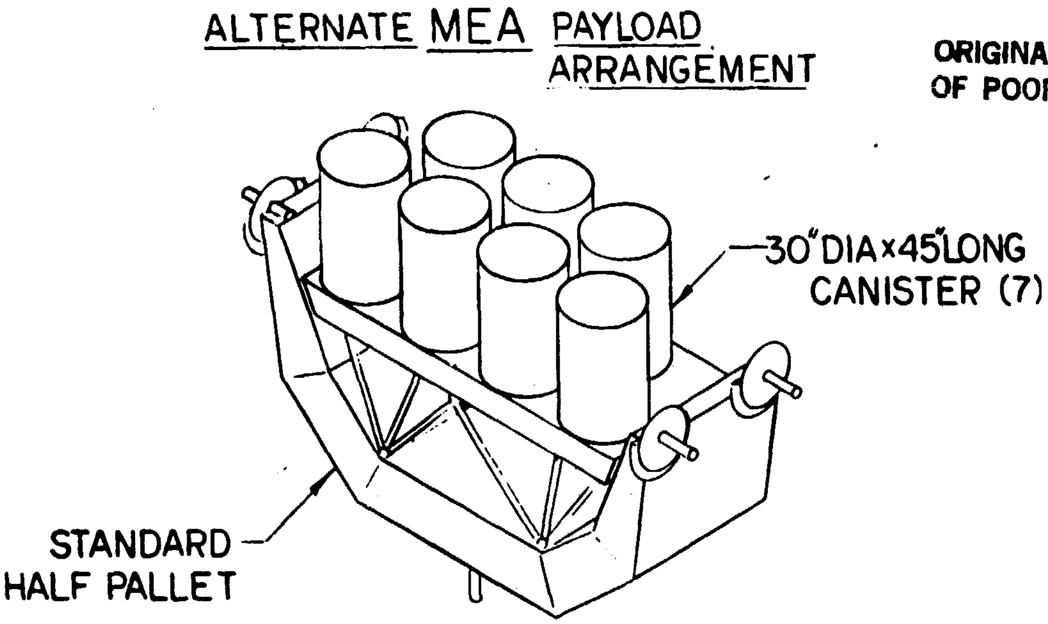

Figure A-5. Sketch MEC2-06

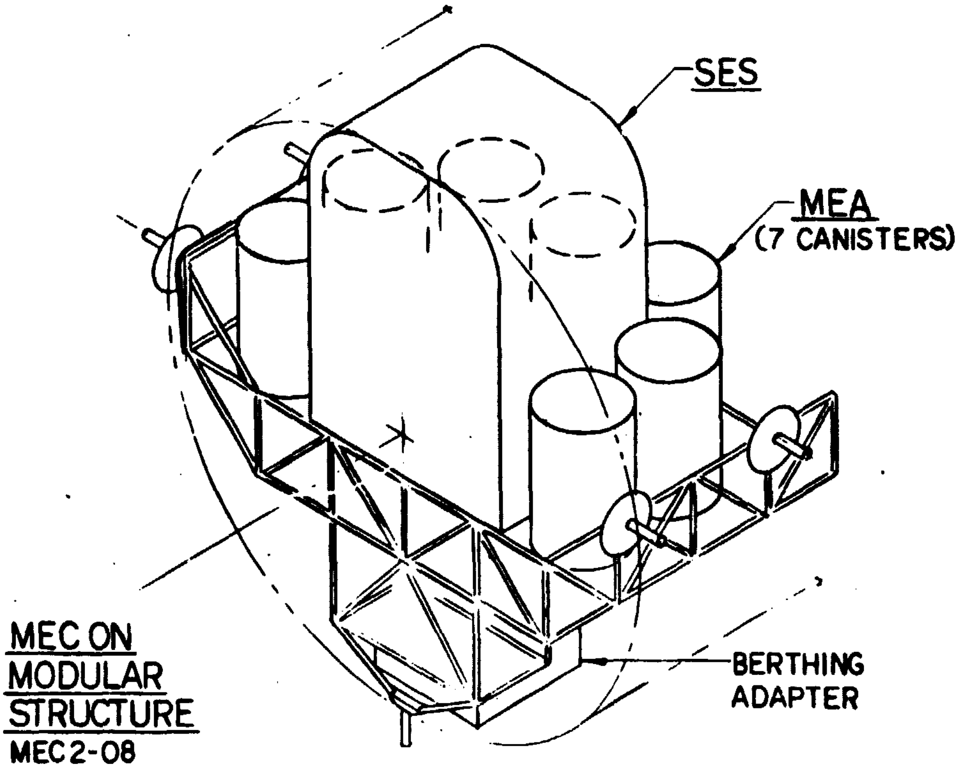

Figure A-6. Sketch MEC2-06

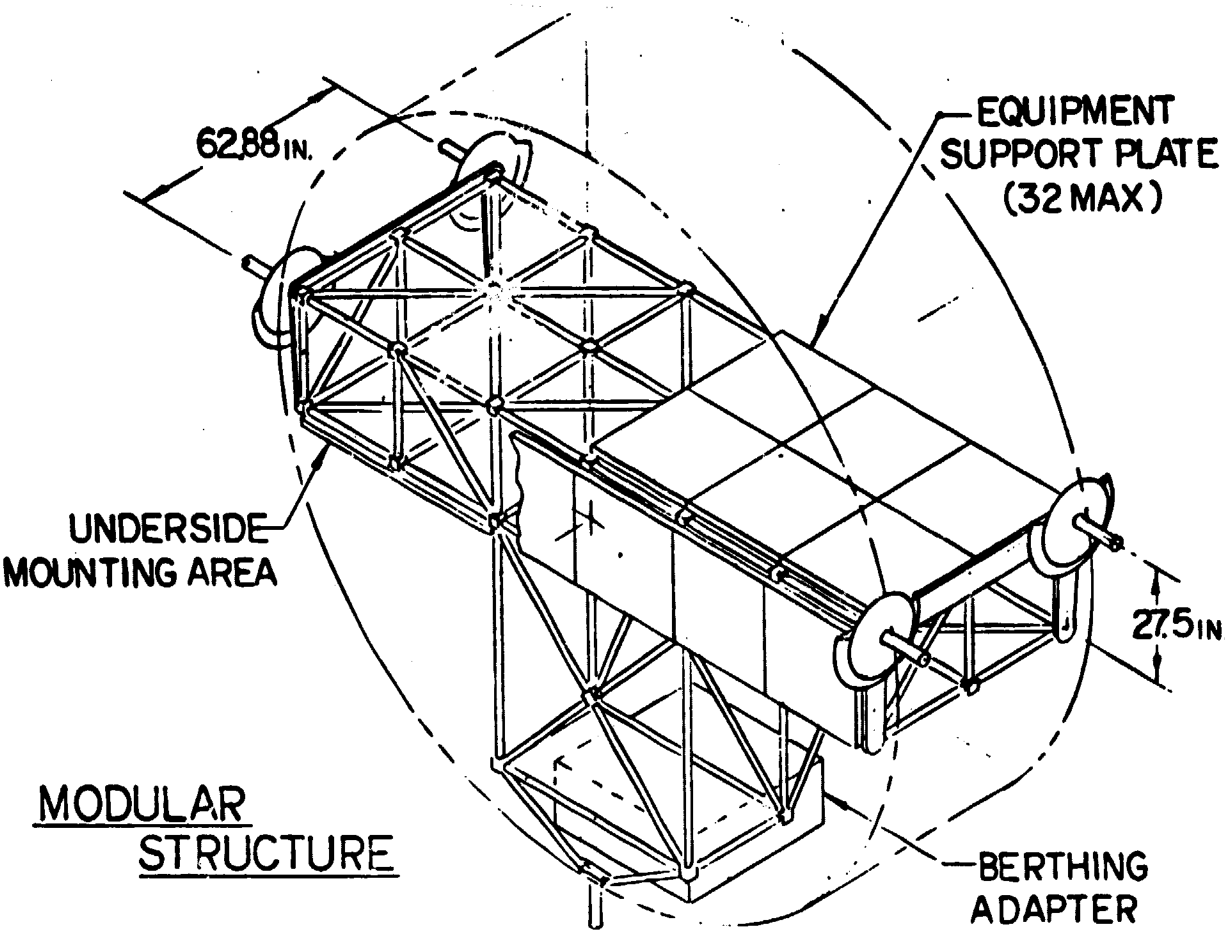

Figure A-7. Sketch MEC2-05

the EOS. The center compartment is used to house MEC subsystems. Accommodation of SES would be possible in one or two peripheral compartments by eliminating MEA canisters.

This arrangement provides convenient payload access, the same as Concept D_1.

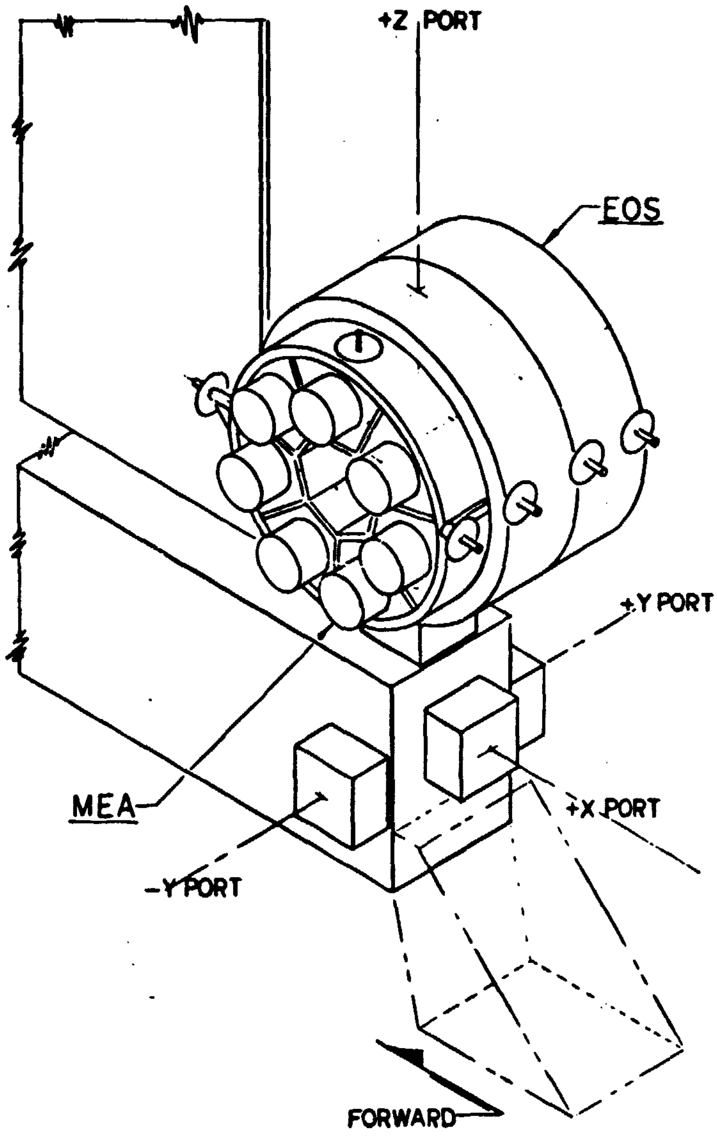

Figure A-8. Concept E_1 (Drawing MEC2-07)

A.8 DUAL SES CARRIER WITH BERTHING PORT (DRAWING MEC2-09)

This unit may be operated as an autonomous MEC or it may be coupled to a variety of other MEC payload carriers as mission requirements dictate. One such coupled MEC arrangement is illustrated by Concept C_1 (Drawing MEC2-03). The dual SES carrier shown there is rudimentary but warrants further consideration. By departing from the SES envelope used in Concept C_1, volume efficiency and payload accessibility are improved. Compartments in the current TRW SES design were rearranged to allow two SES units to be carried side by side on a truss structure, using only five feet of Orbiter bay length. Compared to the dual SES carrier shown in Concept C_1 this is a length reduction of 2.3 feet. Peripheral location of all subsystems equipment which is coldplate mounted, permits on-orbit access. Development of access hatches in the present IRS and sample enclosures would also permit sample magazine changeout. Access to subsystems and samples is not compromised when another MEC payload system is attached to this dual SES carrier.

At least one RMS grapple fixture will be required but selection of its location should be deferred until the mode of operation for this carrier is defined.

A.9 CONCEPT F_1 (DRAWINGS MEC2-10 and MEC2-11)

Drawing MEC2-10 represents a two unit MEC consisting of one MEA/SES Carrier (see Drawing MEC2-11) and an EOS Carrier. These carriers are joined by a SP type berthing device. Advantages realized by using the two-unit approach include:

- Orbiter bay stowage versatility. Two short terms fit more combinations than a single long item.
- Mission assignment flexibility. Either of the two units may be operated as an autonomous system with the SP by omission of the second unit.
- SP position options. Coupled units may occupy x or z berthing ports as indicated by the drawing, but may also be positioned on either +y or -y ports. The two units may also be berthed separately.

The modified EOS carrier envelope shown reflects new data received from MSFC. This envelope facilitates EOS accommodation by MEC. Only one of several possible berthing adapter locations for EOS is shown on MEC2-10, but other locations could be substituted without loss of the functional features of Concept F_1.

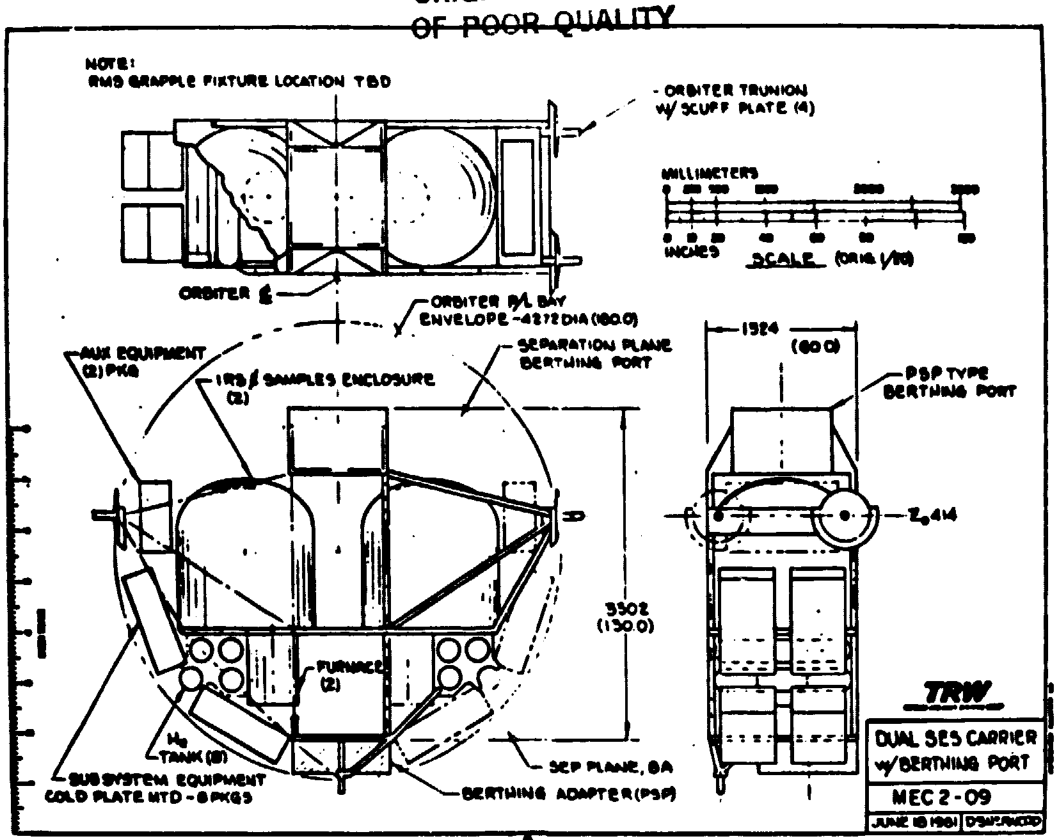

Figure A-9. Dual SES Carrier with Berthing Port (Drawing MEC2-09)

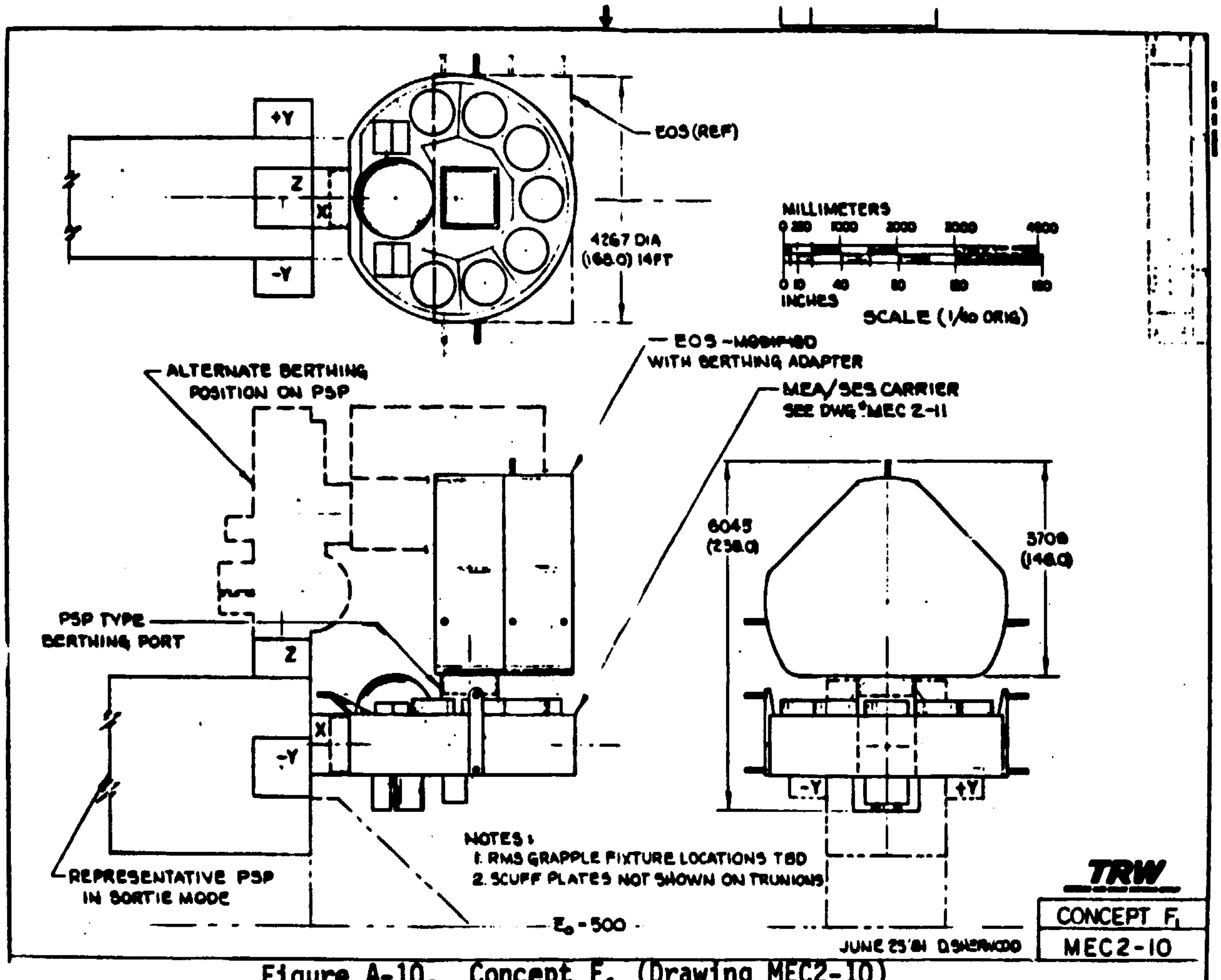

Figure A-10. Concept F_1 (Drawing MEC2-10)

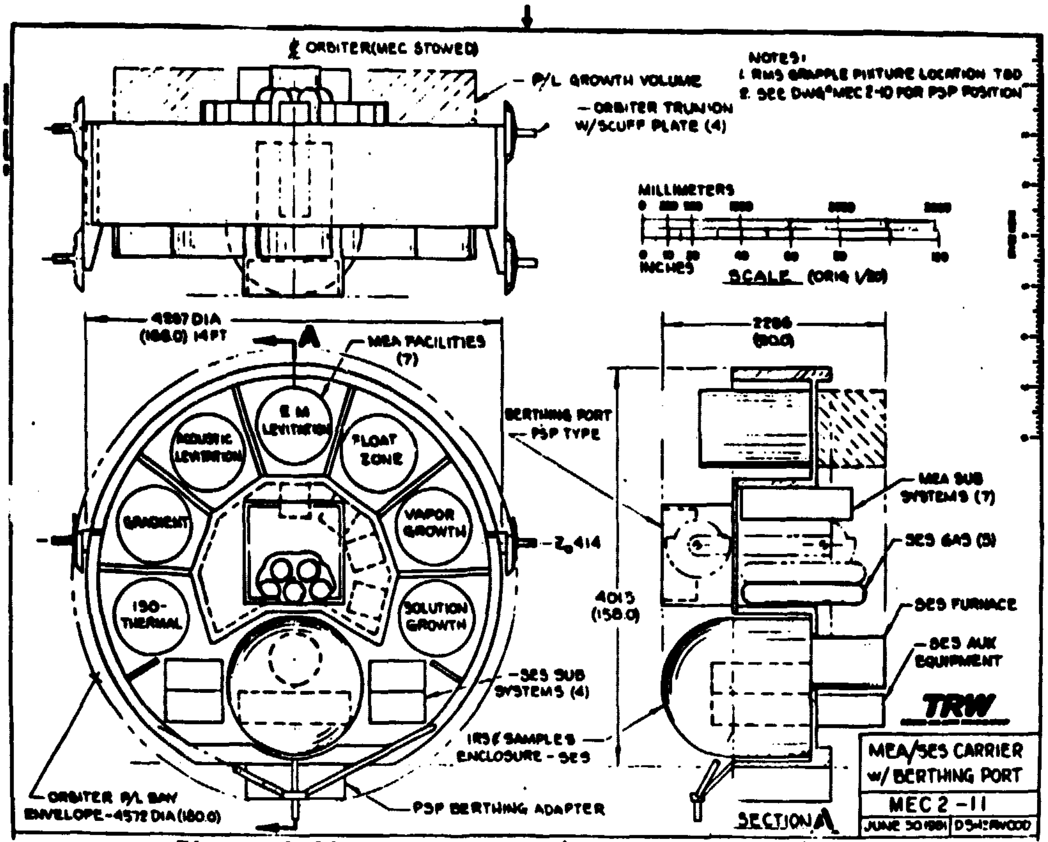

Figure A-10. Concept F_1 (Drawing MEC2-11)

A general arrangement of equipment is shown for the MEA/SES Carrier on Drawing MEC2-11. Size and shape of all components of the present SES design have been preserved in this configuration. SES subsystems packages are mounted to permit on-orbit access without blockage from a berthed EOS carrier. Seven MEA facilities are included in the spoked-disc arrangement, and space is provided for subsystems servicing each facility. Access to the MEA canisters and their subsystems is from the side of the carrier opposite the berthing port. Considerable growth volume exists with this arrangement due to the irreducible length of the SES facility. Space is provided for cables and lines necessary for feed-through of power, signals, and fluids between the SP berthing port and the EOS berthing adapter.

A.10 CONCEPT G_1 (DRAWINGS MEC2-12, MEC2-9 AND MEC2-03)

This concept is illustrated by Drawing MEC2-12 and is basically a two unit MEC with all the advantages covered in the description of Concept F_1.

A separate structural element has been provided to support MEA facilities and their subsystems. This is a spoked-disc configuration which is bolted to the dual SES carrier (MEC2-9) but separable on the ground. The

11.6 foot diameter of the MEA structure fits the SES carrier without overhang. The ground-separable MEA structure facilitates pre-flight integration, testing and transportation.

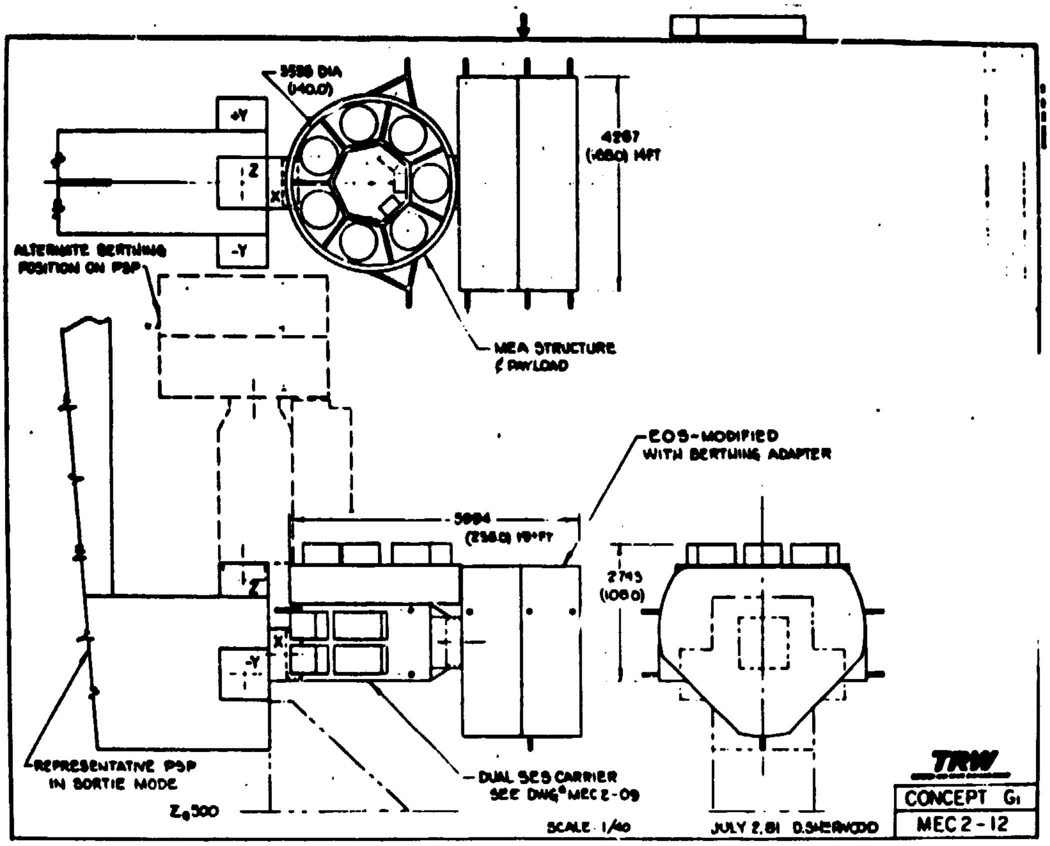

Figure A-11. Concept G_1 (Drawing MEC2-12)

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The EOS carrier for this concept is the modified version as in Concept F_1. An end-mounted berthing adapter is adopted in Concept G_1 to minimize overall coupled length. SP berthing ports x and z are shown as alternate MEC attachment positions. Berthing on the +y or -y ports also may be selected.

A.11 CONCEPTS H_1, J_1, AND K_1 (DRAWINGS MEC2-13, MEC2-14 AND MEC2-15)

A.11.1 Ground Rules

1) Use advanced SES facility - chosen was the facility concept shown on Drawing MEC1-008 with IRS improved per Drawing MEC-011 and a container modified from cylindrical to oval cross section. (20.0"R x 60.0").
2) MEA facilities reference size 30.0" dia x 45.0" long - nine possible processors but not all are required to fly on the same mission. No firm size or required number stated.
3) SES and MEA facilities are to share subsystems to avoid duplication of functional equipment. Subsystems are designated as MEC subsystems and serve any facility combination specified.
4) EOS is to be an autonomous carrier which may be berthed to MEC with power, thermal and data through MEC.
5) Configurations to be investigated using above criteria:
   a. A standard ESA pallet-mounted MEC
   b. A spoked disc with berthing systems mounted axially in the center.
   c. A disc as in b, with the berthing adapter mounted on the side.

A.11.2 Concept H_1 (Drawing MEC2-13, 2 Sheets)

Description

- Uses standard pallet with SP berthing adapter beneath
- Advanced SES facility on pallet floor
- MEA facility compartment bridges pallet
- Berthing port (SP type) mounted on MEA compartment for attachment of EOS
- MEC subsystems mount on pallet floor and are suspended from underside of MEA compartment.

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Advantages

- Large MEA facility compartment accommodates eight reference-sized MEA facilities
- Size and shape of compartment permits growth and change of MEA facilities without structural modification of the compartment
- Two advanced SES facilities can be carried by reducing the 200 cu ft MEC subsystems volume available
- Pallet (concept H_1) may be berthed to any SP port, and EOS attached without interference with other SP ports
- Length of the MEA compartment may be reduced to fit smaller MEA facilities, resulting in weight and cost savings

Disadvantages

- Stack height of H_1 with EOS is 21.3 ft
- Launch weight of H_1 greater than for non-pallet MEC concepts
- Development costs saved by use of the pallet are offset to some extent by development of the MEA facilities compartment
- Orbiter cargo bay length required is dictated by pallet length (9.4 ft)

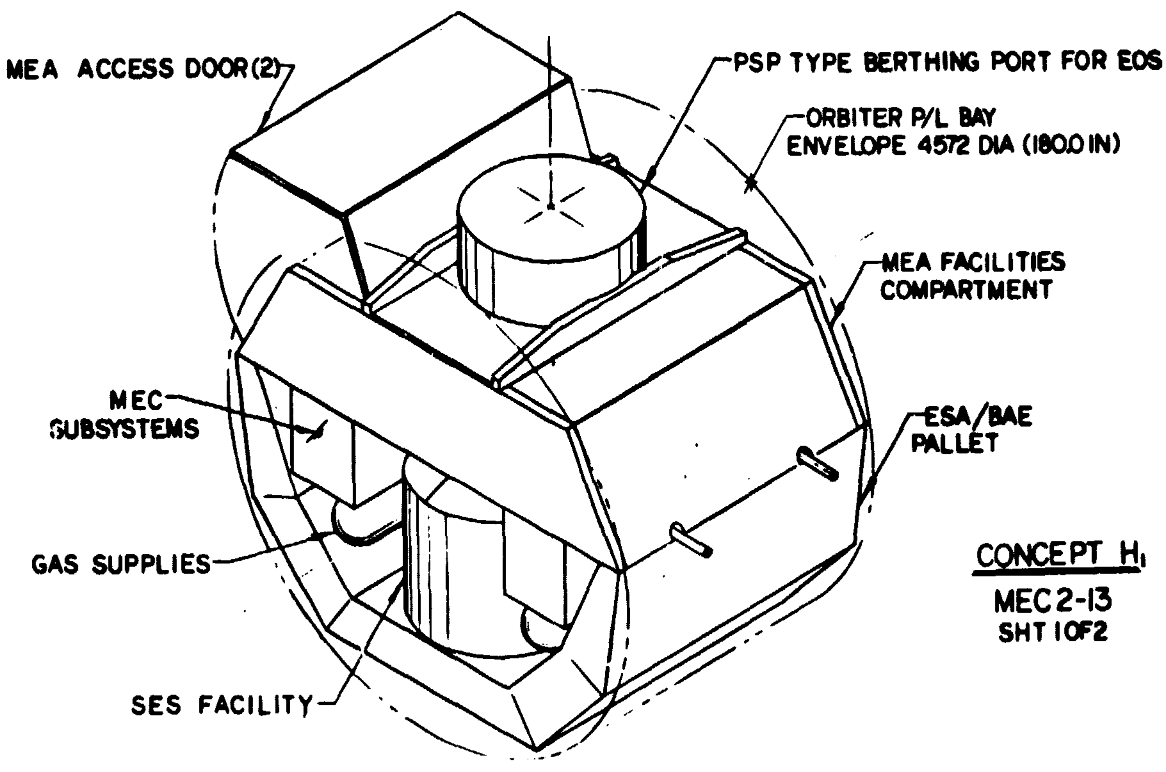

Figure A-12. Concept H_1 (Drawing MEC2-13 - Page 1)

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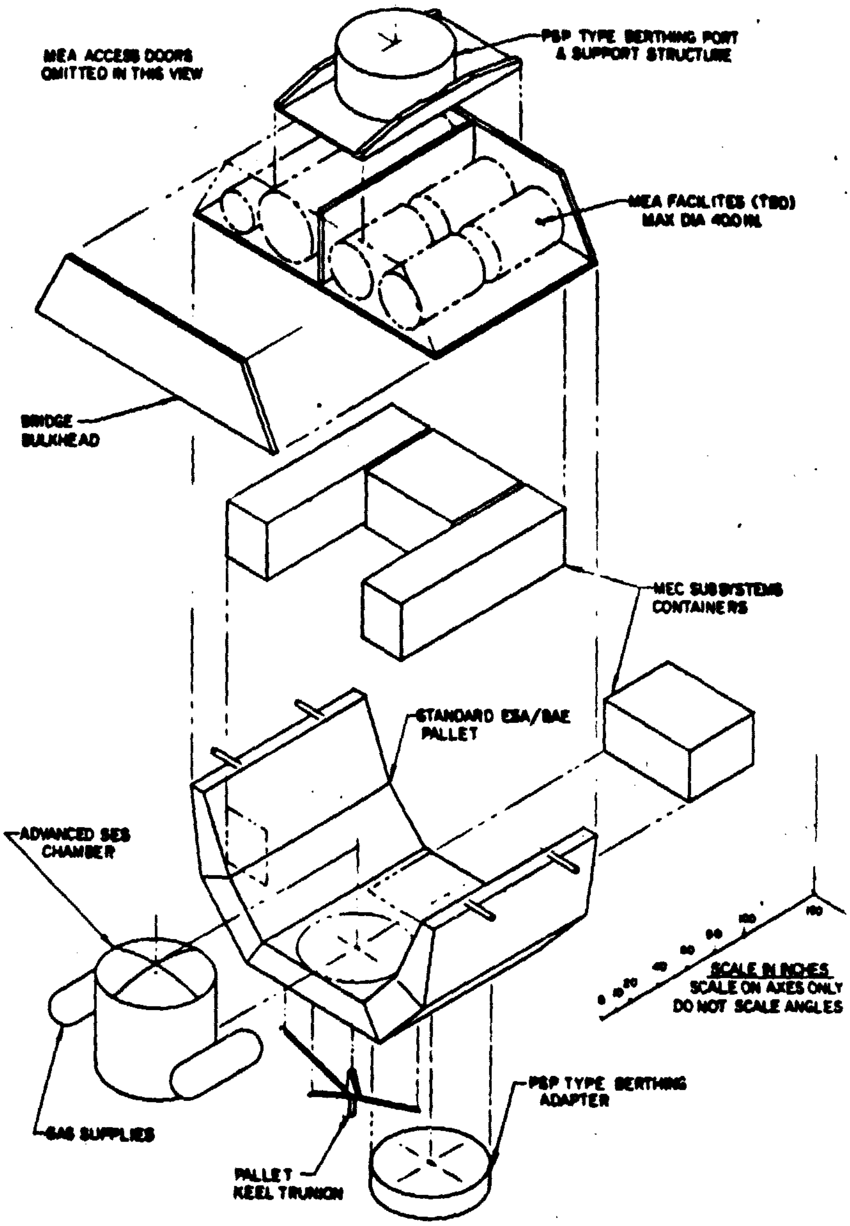

Figure A-13. Concept H_2 (Drawing MEC2-13 - Page 2)

A.11.3 Concept J_1 (Drawing MEC2-14, 2 Sheets)

Description

- Octagonal disc, 40.0" thick
- Advanced SES protrudes axially from disc
- MEA facilities are radially mounted
- Berthing port and adapter are centered on axis
- MEC subsystems mount on access doors and on the EOS facing bulkhead

Advantages

- Structure design is compatible with the MEC subsystem section of MEC configuration Concept B, described in MPS.6-80-287, Technical Report, Volume III (dated 27 February 1981), page 112, Figure 5.2.
- With SES and MEA facilities removed, the structure could be converted to carry subsystems only when attached to an all-up MEC of significantly greater length and capacity
- The EOS berthing port would also be removed reducing overall length to 53.5 inches including the berthing adapter
- Small Orbiter cargo bay length required (6.6 ft)

Disadvantages

- Center location of the SP berthing adapter requires use of SP y ports. Interference anticipated at the x and z ports unless a special adapter unit is furnished
- Radial arrangement of MEA facilities is inefficient, volumewise, but necessary since J_1 is sandwiched between SP and EOS
- Orbital access to SES is blocked when EOS is berthed
- Access doors, and across-hinge service to door mounted subsystems increase development expense and reduce reliability.

A.11.4 Concept K_1 (Drawing MEC2-15)

Description

- Octagonal disc, 45.0 thick
- Advanced SES protrudes axially from disc
- MEA facilities protrude axially from opposite face of disc
- Berthing adapter mounted radially on the longer side of the octagon
- EOS berthing port mounted axially at the center of disc
- MEC subsystems are mounted inside a hexagonal cavity and also externally on the EOS berthing side bulkhead

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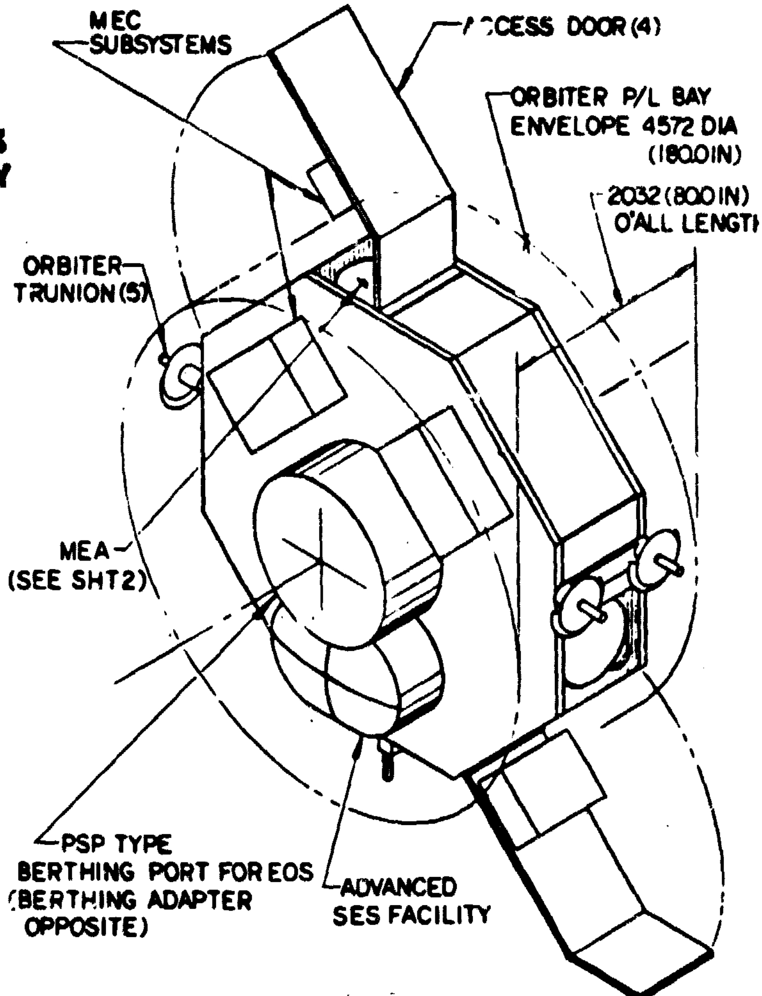

Figure A-14. Concept J_1 (Drawing MEC2-14 - Page 1)

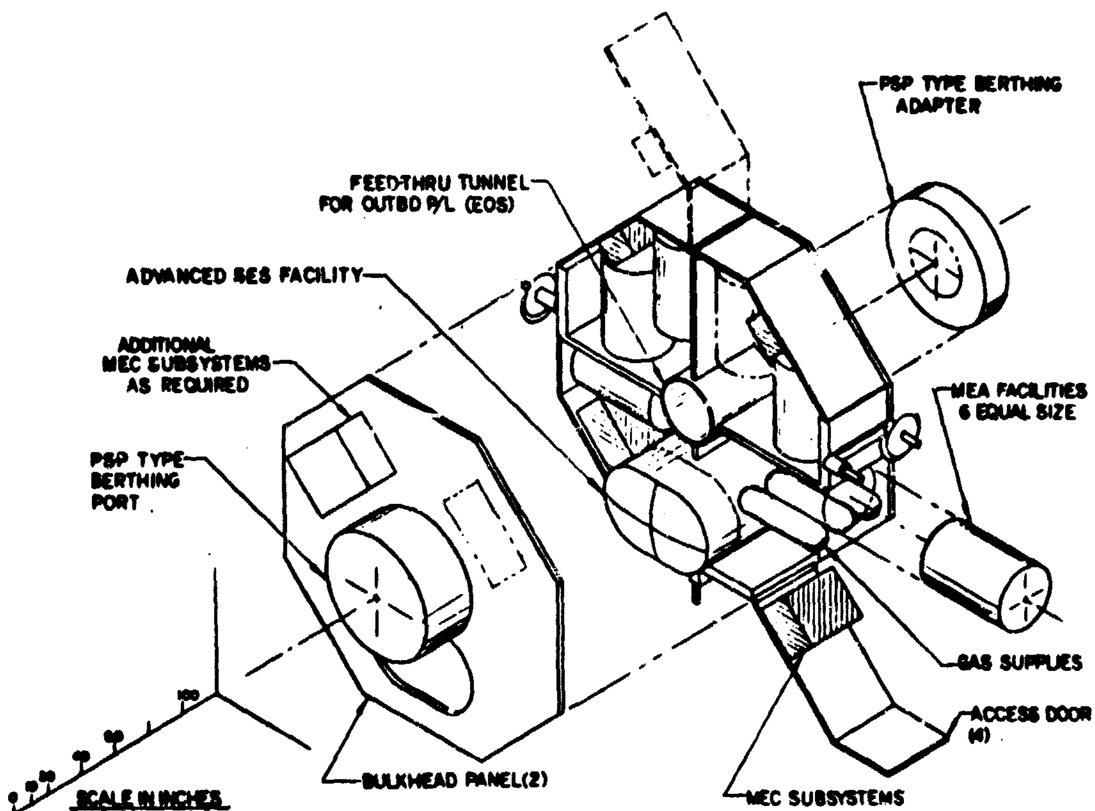

Figure A-15. Concept J_1 (Drawing MEC2-14 - Page 2)

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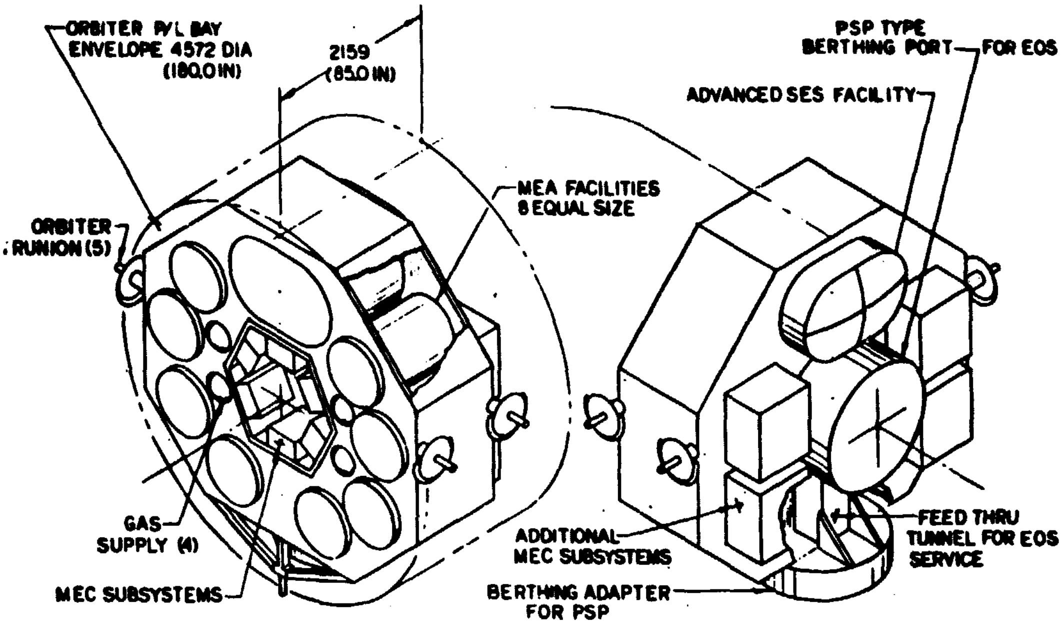

Figure A-16. Concept K_1 (Drawing MEC2-15)

Advantages

- The basic disc structure could be converted to function as a subsystem - only section of a future all-up MEC (configuration B).
- Axial mounted MEA facilities are free to grow, lengthwise, without affecting structure
- K_1 with EOS attached may occupy any SP port
- Access to facilities and subsystems is direct; no doors required on the disc structure
- Exterior load bearing shell structure is volume efficient
- Favorable Orbiter cargo bay length (7.08 ft)

Disadvantages

- Conversion to all-up MEC subsystems-only compartment requires extensive modification
- Some SP berthing locations may infringe on adjacent payload volumes when K_1 has EOS attached

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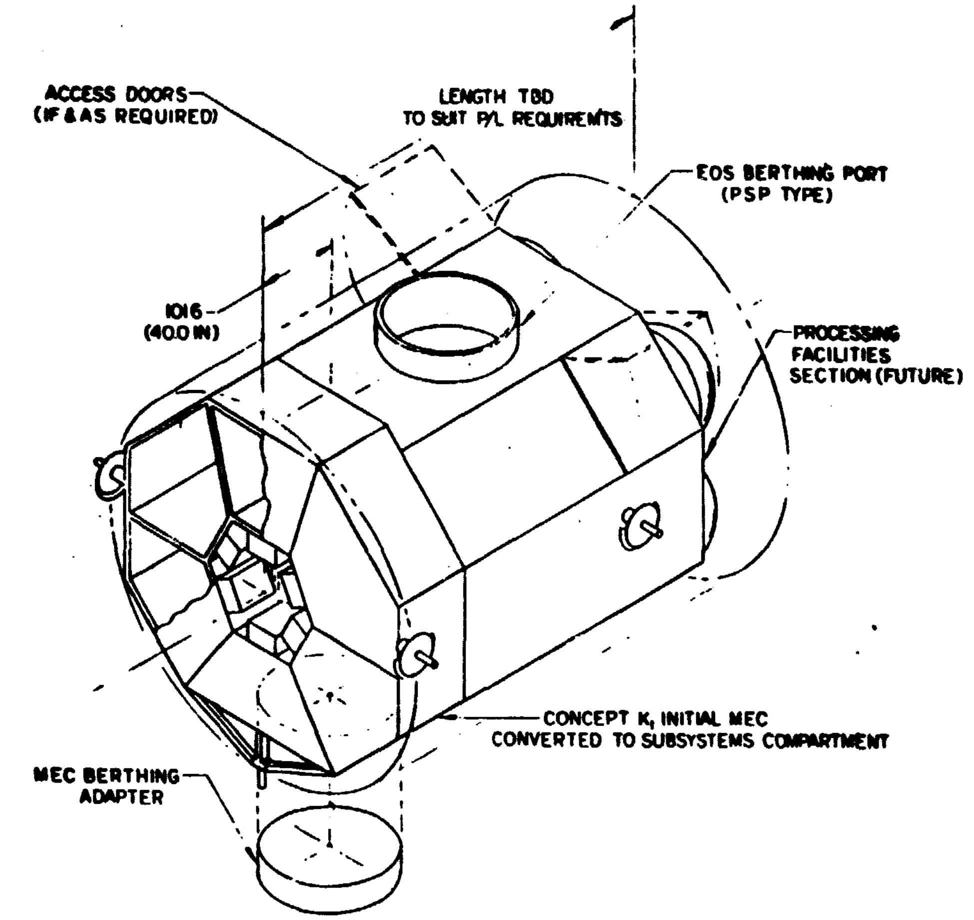

Figure A-17. Growth Concept K_1 (Drawing MEC2-16)

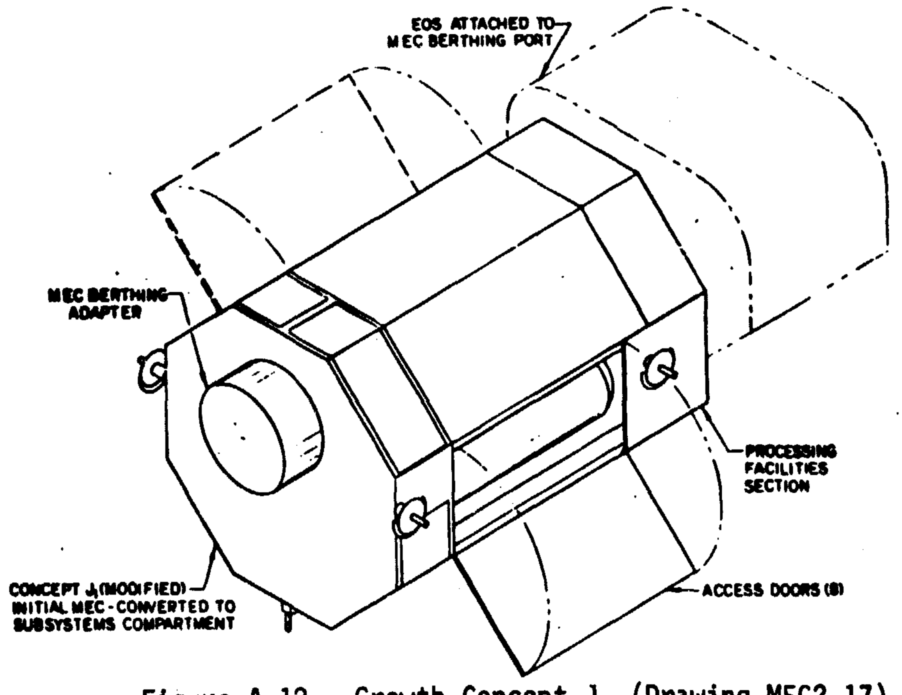

Figure A-13. Growth Concept J_1 (Drawing MEC2-17)

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A.12 CONCEPT L_1 (DRAWING MEC2-18)

This arrangement incorporates suggestions by MSFC at the Configuration Selection Meeting on August 13, 1981.

Using Concept J_1 (Drawing MEC2-14, Sheets 1 & 2) as a departure point, the following modifications were made:

Berthing Accommodations - port and adapter diameter reduced from 60.0 inches to 42.0 inches. Port and adapter location moved off-center to allow SP berthing without a special (35.0 inch long) adapter.

SES Facility - moved to center position, 60.0 inch diameter cylindrical case replaces oval shape to reduce fabrication cost and weight.

MEA Facilities - increased capacity to eight (six are used on J_1).

Structure - same external shape as J_1. All orbital access provisions removed. Solid shell case has ground access only by removal of one large bulkhead.

Growth - similar to that shown on Drawing MEC2-17.

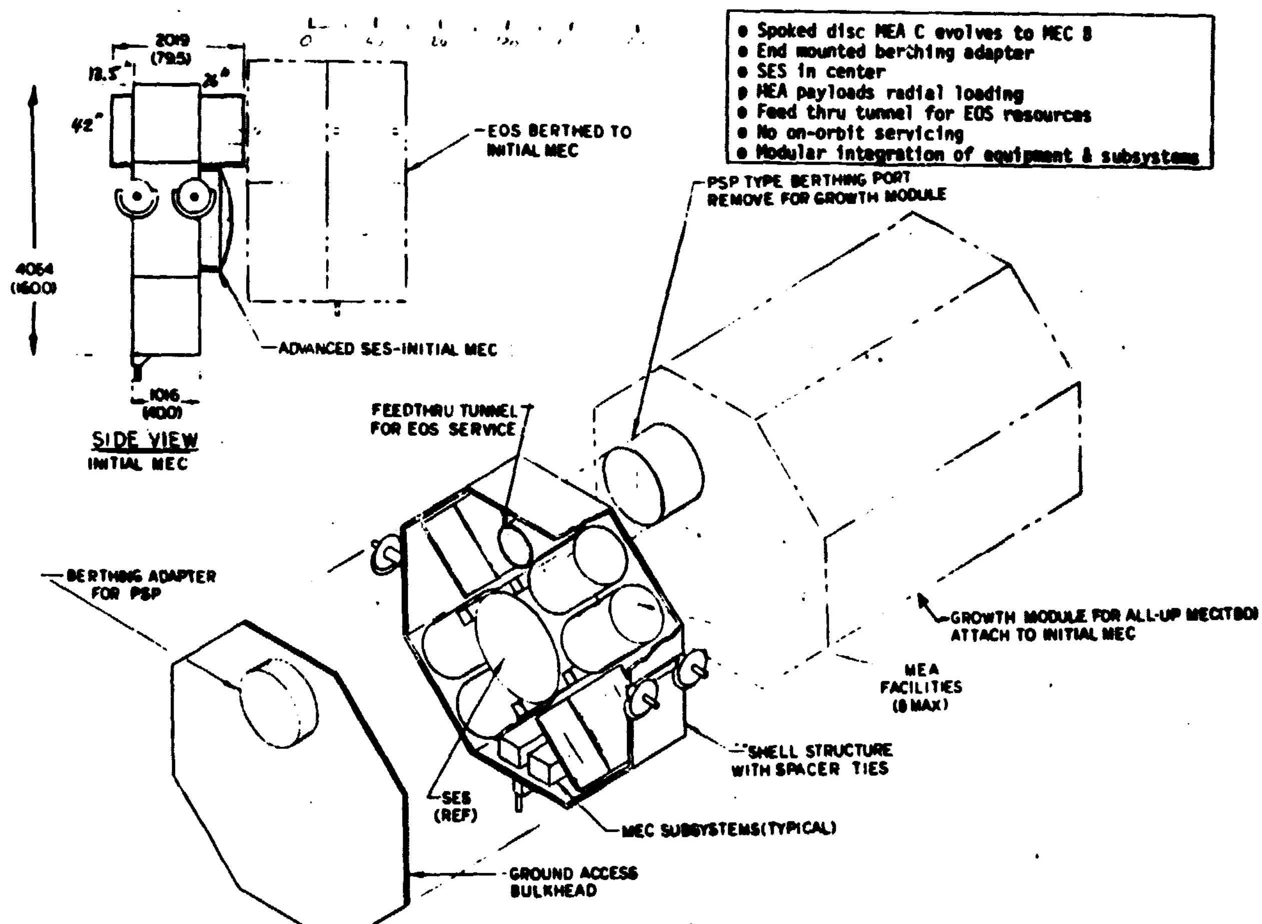

Figure A-19. Concept L_1 (Drawing MEC2-18)

APPENDIX B

EQUATIONS RELATING MEC LENGTH, WEIGHT AND DENSITY CHARACTERISTICS TO SHUTTLE TRANSPORTATION COST

This appendix presents analytical expressions and other data relating MEC length, weight, density and other design factors to Shuttle transportation cost, to support the conclusions reached in Section 6.6.

In the first part, length, weight and density relations are derived that correspond to the "breakeven condition" of length dependent and weight dependent transportation costs (see Section 6.6 and 6.6.3).

In the second part the transportation cost savings achievable by pooling high-density (weight critical) and low-density (length critical) Shuttle payloads are investigated. (See Section 6.6).

B.1 SHUTTLE PAYLOAD CHARACTERISTICS AT LENGTH-WEIGHT BREAKEVEN CONDITIONS

The net Shuttle cargo bay volume V_{MEC} occupied by MEC is related to the MEC net payload weight W_{PL} by the equation

$$W_{PL} = \delta \cdot \gamma \cdot V_{MEC} \qquad (1)$$

where

$$\delta = \frac{W_{PL}}{V_{PL}} = \text{payload density (lb/ft}^3\text{)}$$

$$\gamma = \frac{V_{PL}}{V_{MEC}} = \text{packing factor}$$

The product $\delta \cdot \gamma = \theta = W_{PL}/V_{MEC}$ is termed packing density, a measure of cargo bay volume utilization by the net payload.

Assuming a 14 ft cylindrical cargo diameter the cargo bay volume V_{MEC} and net length L_{MEC} are related by

$$L_{MEC} = \frac{V_{MEC}}{7^2 \pi} = 6.5 \cdot 10^{-3}\ V_{MEC} \qquad (2)$$

A larger "chargeable" length L'_{MEC} and volume V'_{MEC} should be used in transportation cost analysis to take into account items such as MEC berthing adapters and clearance between MEC and other cargo, the added length typically being about 3 ft. Thus $L'_{MEC} = L_{MEC} + 3$ ft

The breakeven ratio between chargeable weight and length of any cargo (as defined in Section 6.6.1) is

$$\left(\frac{W}{L'}\right)_{BE} = 1.0833\text{x}10^3 \text{ lb/ft} \tag{3}$$

for low altitude, low inclination missions (see Figure 6-15).

From the above definitions and Eq. (1) to (3) we derive

$$W_{MEC} = 7.04\ V_{MEC} + 3{,}300 \text{ (lb)} \tag{4}$$

or

$$W_{MEC} = 7.04\ \frac{W_{PL}}{\delta \cdot \gamma} + 3{,}300 \text{ (lb)} \tag{5}$$

Finally, with the payload fraction $q = \frac{W_{PL}}{W_{MEC}}$ substituted as a parameter in Eq. (5), we obtain

$$W_{PL} = \frac{3{,}300}{\frac{1}{q} - \frac{7.04}{\theta}} \tag{6}$$

an equation that relates payload weight, payload fraction q and packing density θ for breakeven conditions.

Figure B-1 shows θ versus W_{PL} with q as parameter based on Eq. (6). Realistic payload fractions are in the range of 0.7 to 0.9 with the upper values typically applying to large systems and large W_{PL}. The graph shows that for the 5000 to 10,000 lb payload weight class representative of MEC values of packing densities range from 8 to 9 lb/ft^3. With a typical packing factor γ of 0.5, this corresponds to payload densities δ around 16 to 18 lb/ft^3. Note that these results apply specifically to weight/length breakeven ratios of Shuttle payloads. Higher densities generally would reflect a shift into the weight-critical regime in the weight/length diagram (Figures 6-15 and 6-16 in Section 6) above the breakeven line.

Figure B-2 is a parametric plot of payload density δ versus net length L_{MEC} for constant values of paylaod weight W_{PL} (solid lines), based on Eq. (1) and (2), and payload fraction q (dashed lines) derived from Eq. (6). A packing factor $\gamma = 0.5$ is assumed here.

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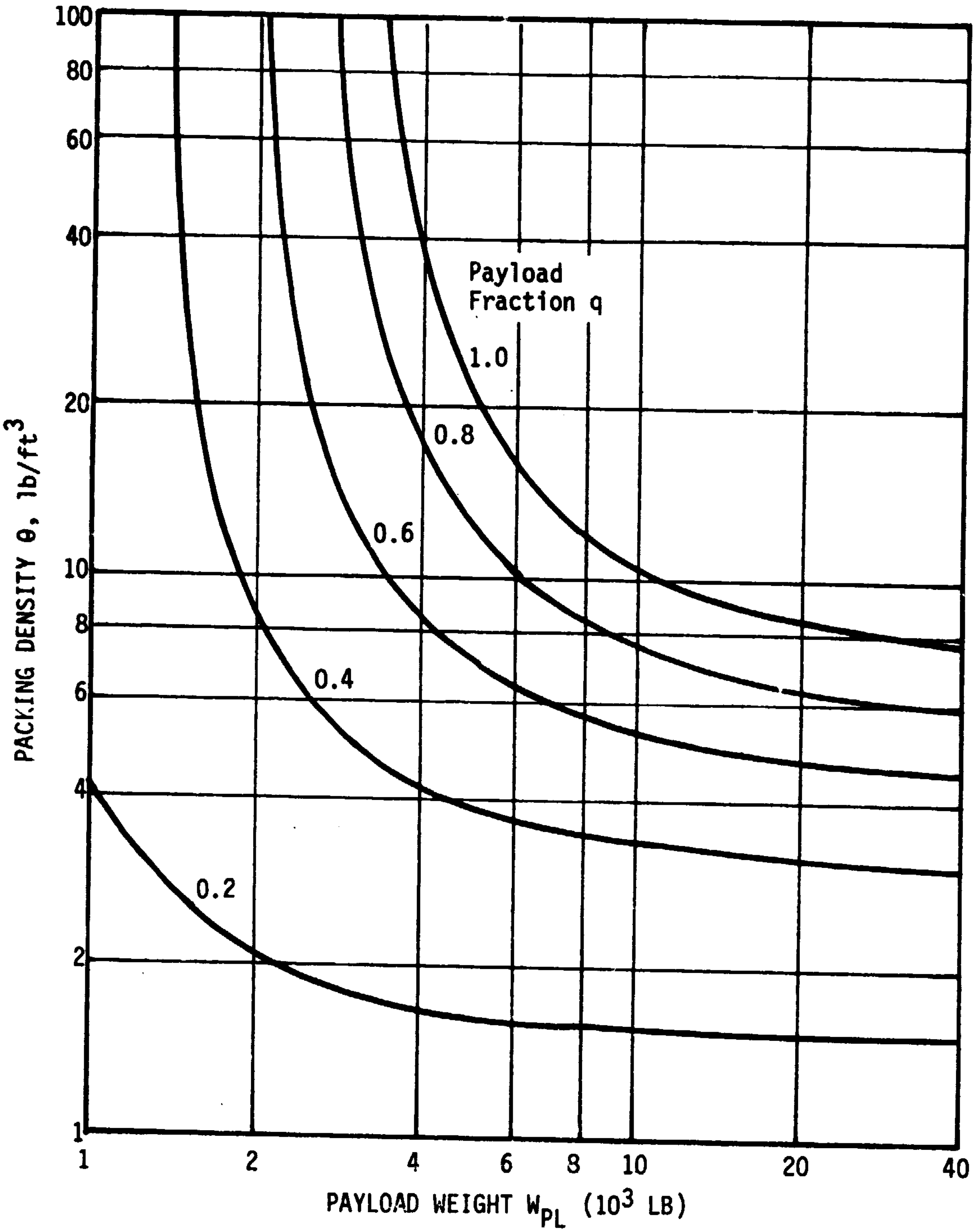
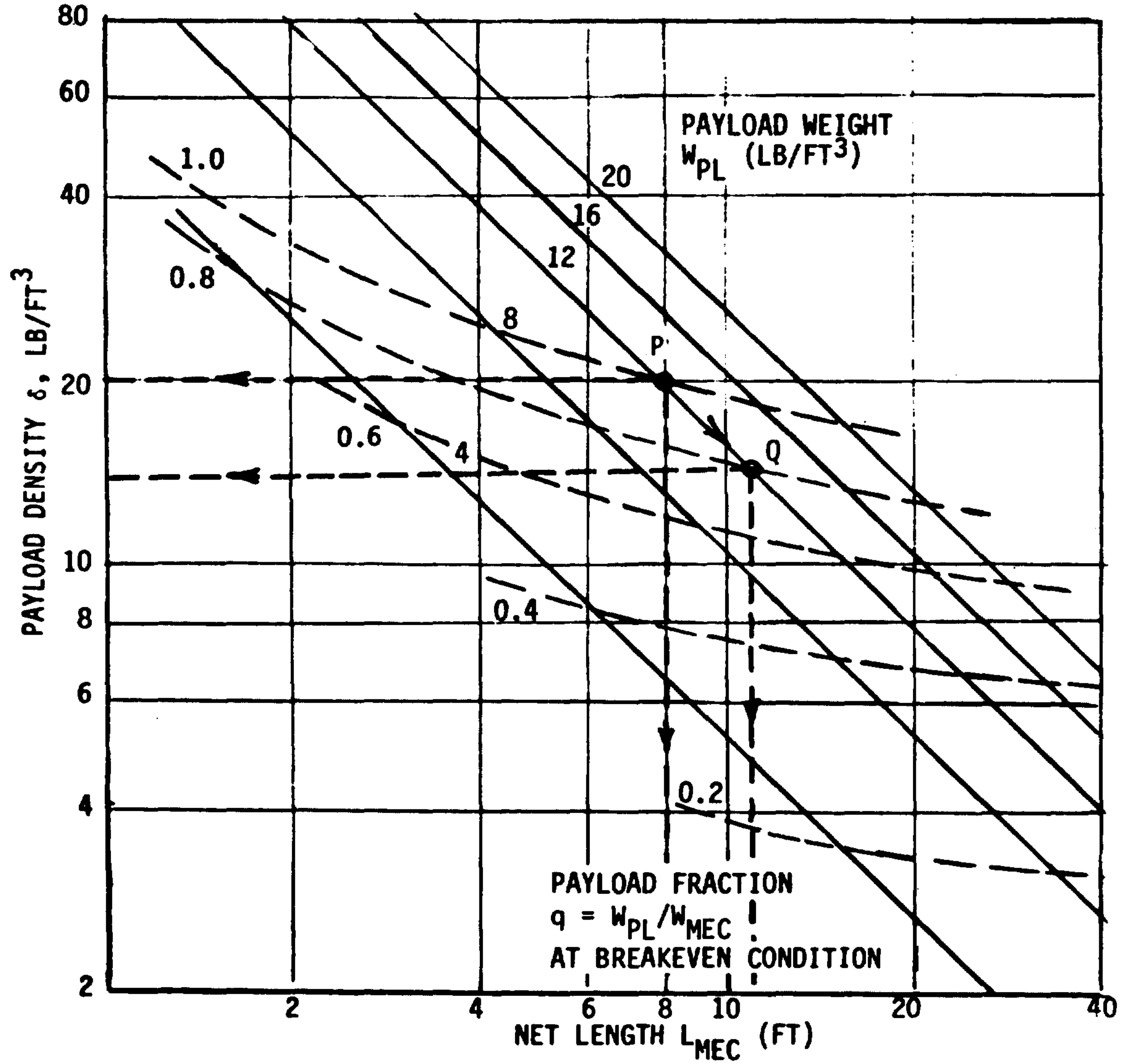


Figure B-1. Packing Density vs. Payload Weight With Payload Fraction q as Parameter

(PACKING FACTOR γ=0.5)



EXAMPLE:

W_{PL}=12000 LB
L_{MEC}=8 FT
δ=20 LB/FT^3
Reflects in 100% payload fraction q at breakeven condition (point P)

Reduction of payload fraction to 80% results in
δ=15 LB/FT^3
L_{MEC}=11 FT
(point Q)

Figure B-2. Payload Density vs. MEC Length and Weight

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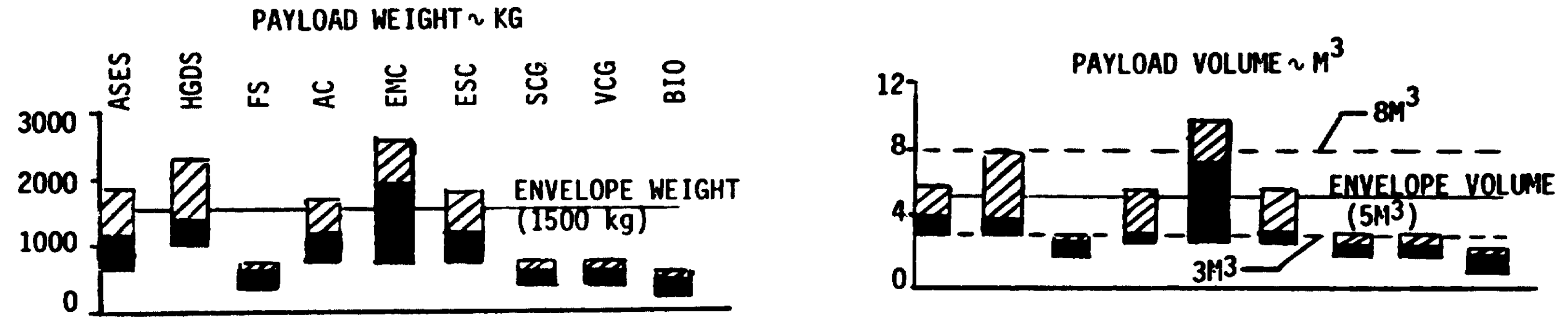
The examples shown by points P and Q in Figure B-2 as explained in the legend correspond to breakeven conditions, with P at 20 lb/ft^3 density representing an unrealistic payload fraction ($q=1$), Q at 15 lb/ft^3 density a realizable value, $q = 0.8$. (See also the corresponding data at P and Q in the nomograph, Figure 6-17).

Figure B-3 shows representative weights, volumes and densities of prospective MEC payloads, based on the payload survey performed in MEC Study Part 1. As a rough estimate, the densities shown in the bar graph at the lower right were derived from the upper and lower payload weight and volume limits from the bar graphs above. These densities range from 13 to 21 lb/ft^3 with an average of about 16 lb/ft^3 and are therefore compatible with the previously derived representative payload densities for cost-effective MEC Shuttle launch at or near the weight/length breakeven condition.

Length and weight estimates for the initial MEC (see Figure 6-16) are close to breakeven, in agreement with the above results. Those for the all-up MEC extend far into the weight-critical regime due to large estimated maximum payload weights (3000 lb) and the conservative assumption that all payloads carried might be in the maximum weight class. A need for increasing payload density is not borne out by this analysis.

The above results are summarized as follows:

1. For a given payload weight (W_{PL}) the density δ implies payload volume V_{PL}; the packing factor γ implies MEC volume in cargo bay, hence lengths L_{MEC} and L_{MEC}.
2. Results show that for a practical range of payload fractions ($q = 0.7$ to 0.9) breakeven conditions correspond to densities below 20 lb/ft^3. Higher densities would result in weight-critical STS transportation costs.
3. Typical densities of prospective MEC payloads investigated in MEC Study Part 1 range from 13 to 21 lb/ft^3, and are therefore compatible with cost-effective Shuttle launch at or near the weight/length breakeven ratio.



PAYLOAD NOTATION

ASES-Advanced Solidification Experiment System
HGDS-High Gradient Directional Solidification
FZ - Float Zone
AC - Acoustic Containerless
EMC- Electromagnetic Containerless
ESC- Electrostatic Containerless
SCG- Solution Crystal Growth
VCG- Vapor Crystal Growth
BIO- Bioprocessing

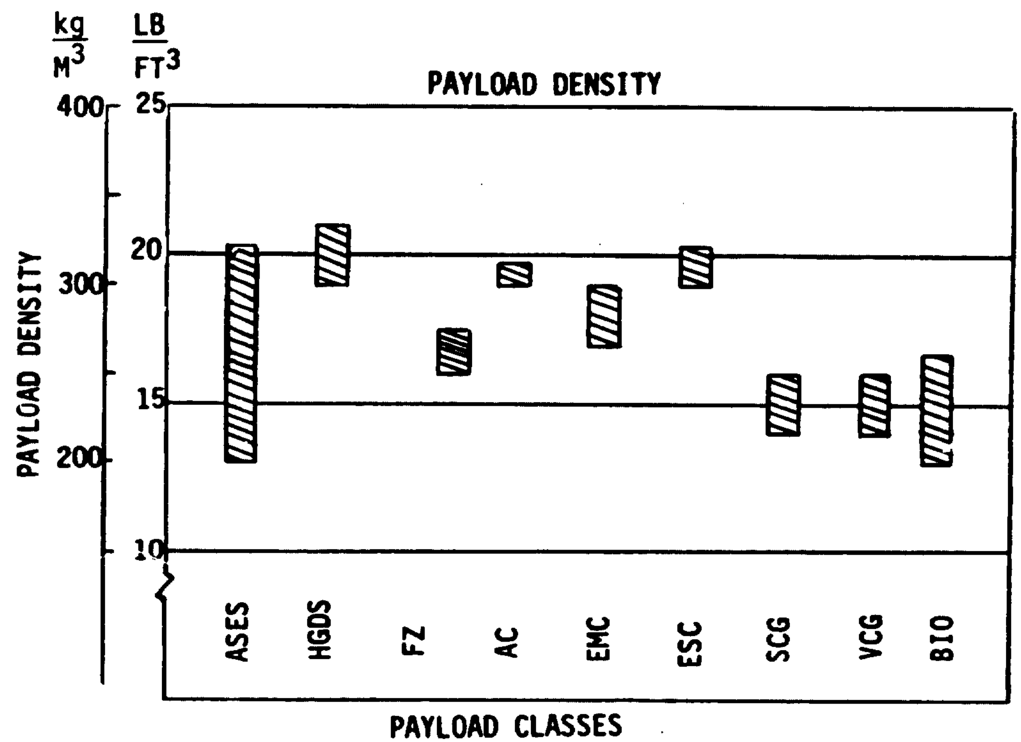


Figure B-3. Payload Weights, Volumes and Densities*

*Based on results of MEC Study, Part 1

B.2 TRANSPORTATION COST SAVINGS ACHIEVABLE THROUGH PAYLOAD POOLING

The NASA policy defining Shuttle user charges (Reference 19) permits substantial cost savings by payload pooling arrangements whereby a high-density (weight-critical) payload would be matched with a low density (length-critical) payload such that the combined cargo weight/length ratio comes close to cost-effective breakeven conditions. The objective is to combine complementary payloads so as to make full use of Shuttle cargo capacities, avoiding waste of lift-off weight or cargo bay volume.

The incentive for the user is to avoid the extra charge associated with weight or length "overrun," i.e., deviation from the breakeven line. This can be accomplished, e.g., by offering unused cargo bay length left over as a result of having a weight-critical payload to another user with a length-critical payload. In other words, the weight overrun of one payload provides a length margin for the companion payload and vice versa, Figure B-4 (see also the discussion in Section 6.6.1).

A second factor is the 33.3 percent "mark-up" each user is normally being charged in the STS reimbursement algorithm, viz.,

$$C_W = 1.33 \frac{W_{cargo}}{W_{capacity}} \times \text{dedicated Shuttle launch cost}$$

which is intended to cover the left-over capacity to be anticipated in typical launch situations. The incentive for cost reduction in this case is to let the second user take advantage of the projected "plateau" in the cost function (see Figure B-4,also Figure 6-14) that may not be used by the first user. This would in effect reduce the total mark-up payable by both users.

Conversations with the STS Operations Resources Analysis Office at NASA/Johnson Space Center have affirmed this cost incentive to effective Shuttle payload pooling by Shuttle users, although it is not explicitly referred to in the STS Reimbursement Guide (Reference 19). User initiative in this area helps facilitate the cargo manifesting task facing NASA.

The following paragraphs summarize results of an analysis of cost savings achievable by cargo pooling. The first part is based on the simplifying assumption that two users fully utilize all of the STS cargo bay length or cargo weight lift-off capacity.

In reality, there will of course always be some left-over cargo length and weight capacity that reduce the full cost benefits derived in the idealized case. This effect is reflected in the second part of the analysis. An extension of the analysis is recommended which would consider pooling of more than two users' payloads.

1. Ideal Payload Matching

It is assumed here that the two payloads are ideally matched in length or weight. This implies that either the length margin of payload 1 is fully used up by the length overrun of payload 2 or vice versa. In the former case payload 1 is weight-critical, in the latter case it is length critical. The resulting cost savings on both sides of the breakeven line are equivalent. Therefore, the results obtained for one case also apply to the other case, with savings contours in the weight vs. length diagram being symmetrical with respect to the breakeven line (Figure B-5).

Let the user charge for payload 1 be proportional to the percentage p_{w1} of weight capacity used by it. The companion payload (payload 2) will be charged in proportion with the percentage p_{12} of length capacity used. Thus

$$c_1 = m\, p_{w1}$$
$$c_2 = m\, p_{12} \tag{7}$$

It is assumed that $p_{w1} + p_{12} = 1$ (no left-over capacity). Both users thus pay the full (dedicated) cost of the launch,

$$c_1 + c_2 = 1 \tag{8}$$

or

$$m\,(p_{w1} + p_{12}) = 1 \tag{9}$$

$$m = \frac{1}{p_{w1}+p_{12}} \tag{10}$$

Normally users 1 and 2 would be charged

$$c_{10} = 1.333\, p_{w1}$$
$$c_{20} = 1.333\, p_{12} \tag{11}$$

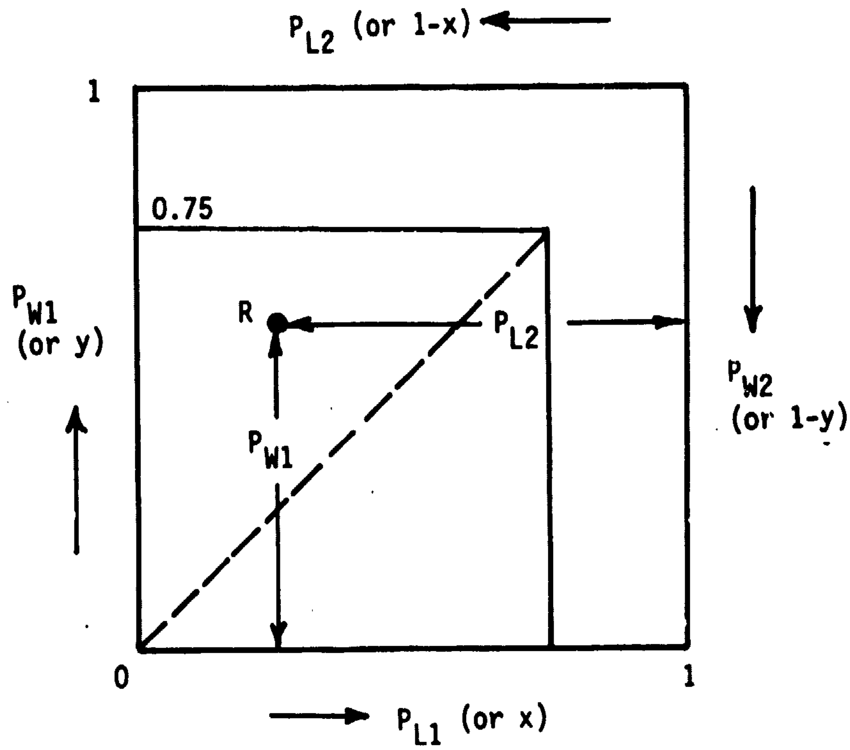


Figure B-4. Ideal Payload Matching At Point R

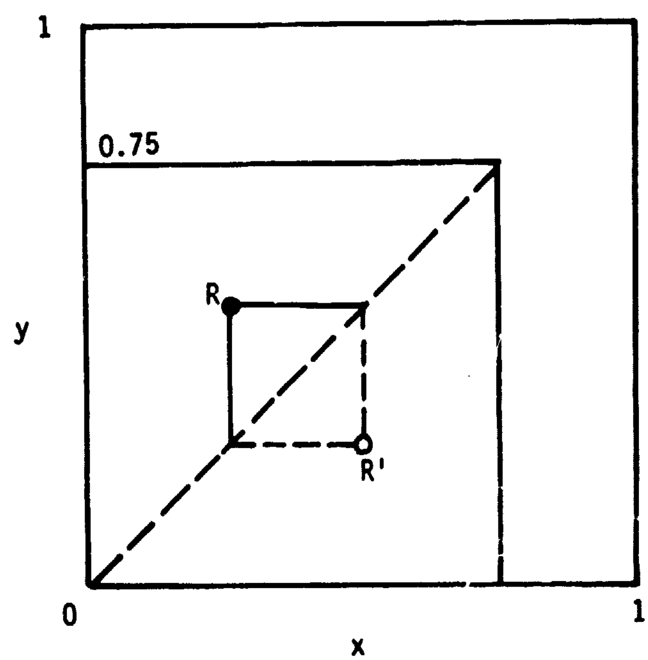


Figure B-5. Symmetry of Cost Savings at Points R and R'

Cost savings for user 1 due to ride pooling will thus be

$$\Delta c_1 = c_{10} - c_1 = (1.333 - m)\ p_{w1} \tag{12}$$

Using Eq. (7), (10) and (11) we obtain the relative cost savings of user 1 and 2

$$\frac{\Delta c}{c_0} = 1 - \frac{3m}{4} \tag{13}$$

This result applies in the "linear region" of charges in the W-L plane. Using the simplified notation in a W-L plane with coordinates x and y

$$p_{w1} = y \qquad (0 < y < 1)$$

$$p_{12} = 1-x \qquad (0 < x < 1)$$

We obtain

$$m = \frac{1}{y-x+1} \tag{14}$$

Thus

$$s = \frac{\Delta c}{c_0} = 1 - \frac{3}{4}\ \frac{1}{y-x+1} \tag{15}$$

This determines the cost saving contours, s=constant, shown in the linear part of the x-y plane Figure B-6.

Corresponding analysis applying to the "plateau" (non-linear part) of the x-y plane results in

$$s_p = 1 - \frac{y}{y-x+1} \tag{16}$$

Note that at the breakeven line the cost savings are 25%. This contour separates at the plateau corner into two slanting branches with slopes of $-\frac{2}{3}$ and $-\frac{1}{3}$. The 50% contours consist of branches with slopes of +1 and -1 passing through the points x=0, y=1 and x=1, y=0. The theoretically highest cost savings are 57% at the points x=0, y=0.75 and x=0.75, y=0. Figure B-7 shows a cross-section through the s-contours in the linear part of the x-y plane, plotted versus the parameter $k=y-x+1$ $(=\frac{1}{m})$. The values vary from s=0.25 at the center to 0.57 at k=0 and 1.5.

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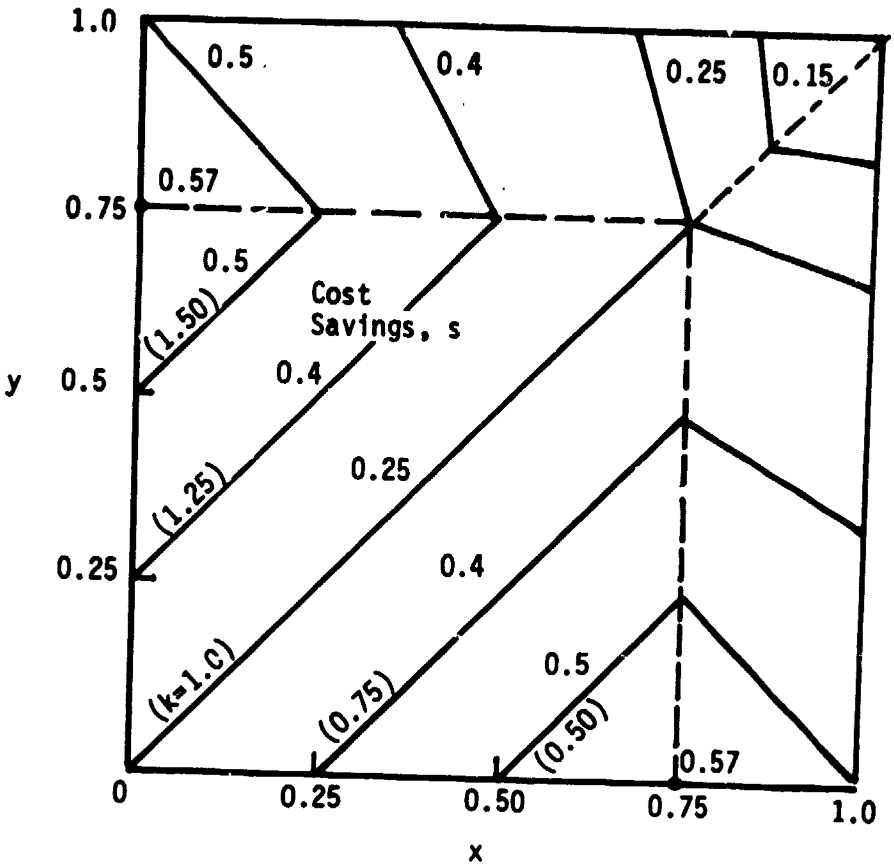

Figure B-6. Cost Savings Contours in x-y Plane
(Ideal Payload Matching)

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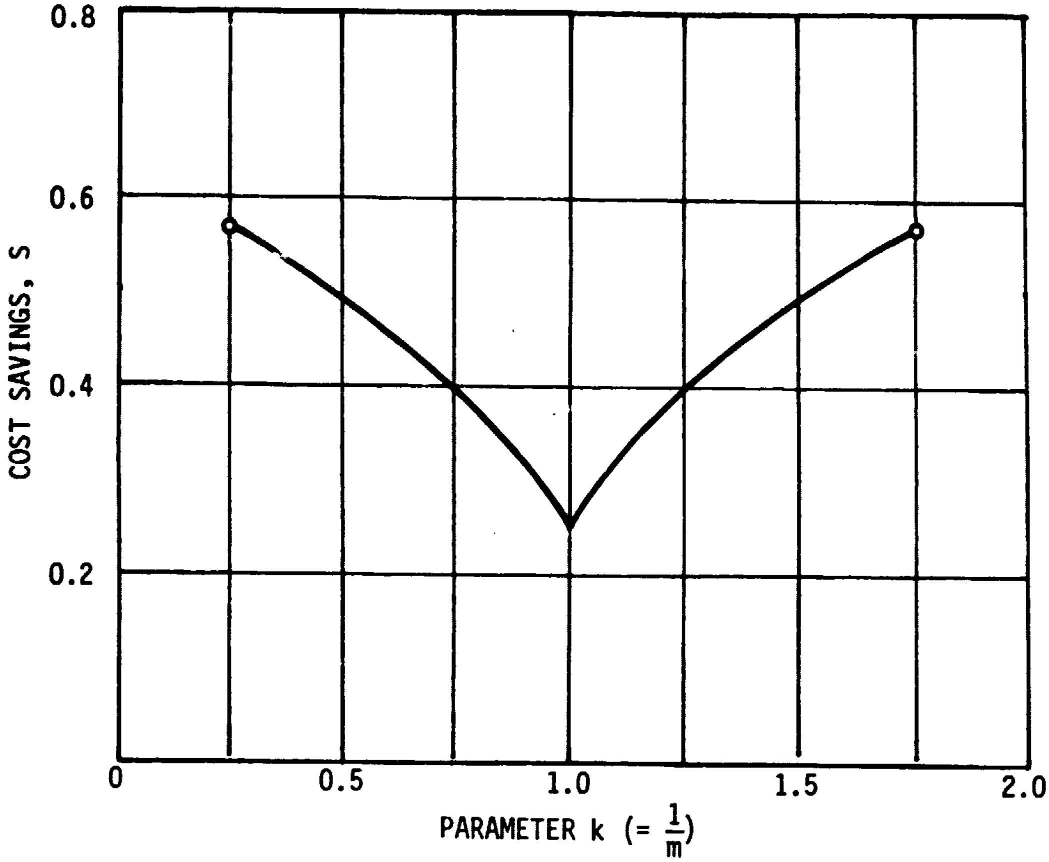

Figure B-7. Cross Section through Cost Savings Contours in x-y Plane (along line y-0.75-x) vs. parameter k (=$\frac{1}{m}$)

2. Non-ideal Matching

The analysis considers the situation, depicted in Figure B-8, where payloads 1 and 2 are matched non-ideally leaving unused capacity in weight (δ_w) and length (δ_l):

$$p_{w1} + p_{w2} = 1 - \delta_w \qquad (17)$$
$$p_{l1} + p_{l2} = 1 - \delta_l$$

The relative savings $\bar{s}$ in this case, expressed in x,y coordinates then become

$$\bar{s} = 1 - \frac{3}{4} \frac{1}{y-x+1-\delta x} \qquad (18)$$

for the linear part of the x-y plane.

The reduction from ideal savings s is given by

$$\Delta s = s - \bar{s} = -\frac{3}{4} \left(\frac{1}{y-x+1} - \frac{}{y-} \;\; \frac{1}{1-\delta x} \right)$$
$$= \frac{3}{4} \frac{\delta x}{(y-x+1) \;(\;\; -x+1-\delta x)}$$

For small δx this is approximated by

$$\Delta s \approx \frac{3}{4} m^2 \delta x \qquad (19)$$

The relative reduction in savings is approximately

$$\frac{\Delta s}{s} \approx \frac{m^2}{\frac{4}{3} - m} \delta x \qquad (20)$$

Figure B-9 shows the loss in cost savings s due to mismatch δx based on the above relationships. It depends on distance from the breakeven line, or $\Delta = y - x$. In the example $\Delta = 0.2$ a mismatch $\delta x = 0.2$ reduces the cost savings from the ideal value 0.375 at $\delta x = 0$ to 0.25, i.e., by one third.

3. Conclusions

In conclusion the potential cost savings achievable ideally through payload pooling can be as large as 50 percent. However, even with an appreciable mismatch of payload length or weight major cost savings will be realized. Even if reduced to 20 or 25 percent, in the non-ideal case the savings could be of the order of $5 million or more in some instances.

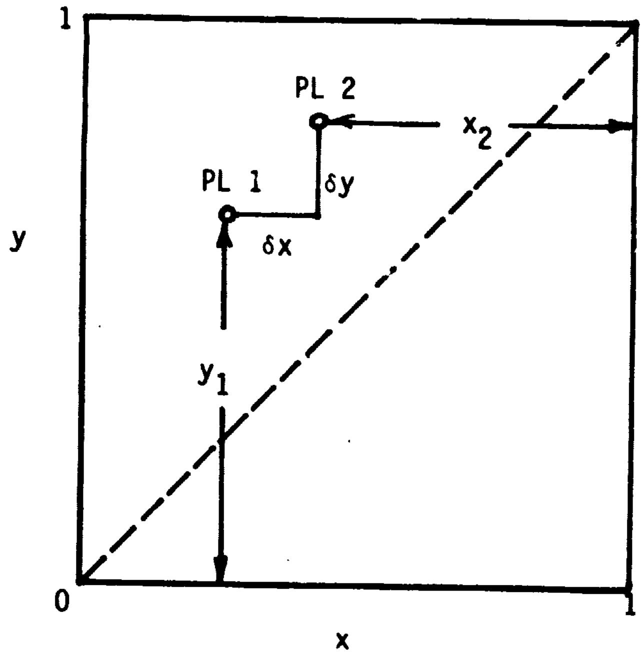

Figure B-8. Non-Ideal Payload Matching

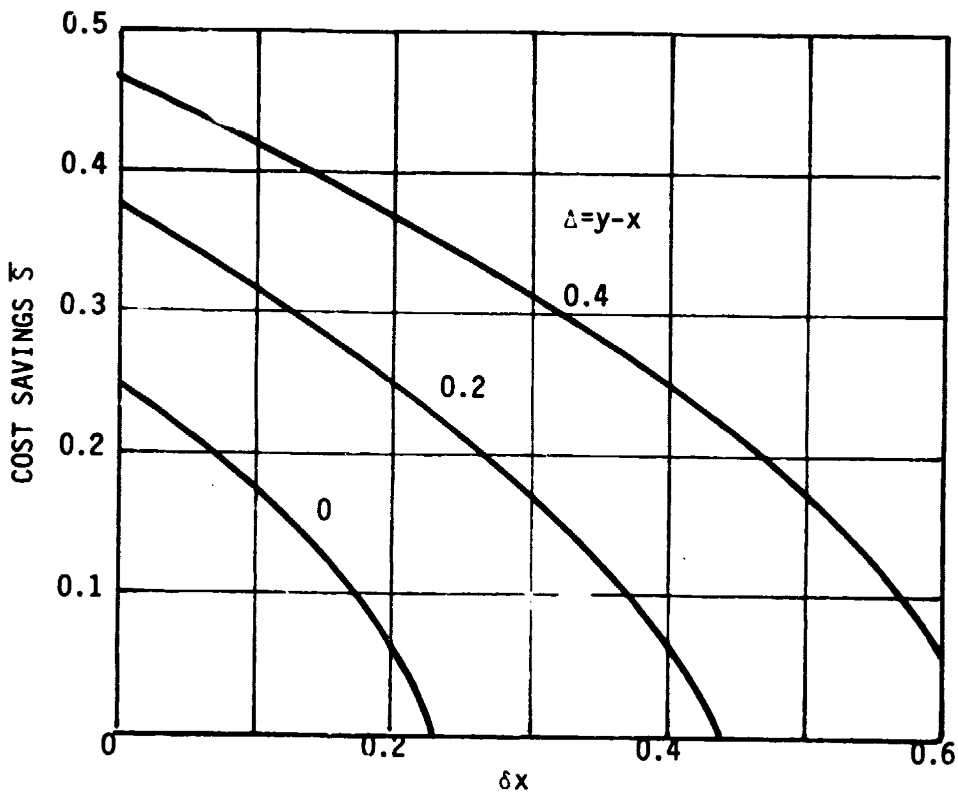

Figure B-9. Cost Savings in Non-Ideal Payload Matching vs. Mismatch δx With $\Delta = y - x$ as Parameter